DOCUMENT RESUME

ED 096 154 SE 018 073

AUTHOR	Holmes, Jay, Ed.
TITLE	Energy, Environment, Productivity. Proceedings of the First Symposium on RANN: Research Applied to National Needs, November 1973.
INSTITUTION	National Science Foundation, Washington, D.C. RANN Program.
PUB DATE	May 74
NOTE	253p.
AVAILABLE FROM	Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 (Stock No. 3800-00177, $3.40)
EDRS PRICE	MF-$0.75 HC-$12.60 PLUS POSTAGE
DESCRIPTORS	*Economics; *Energy; *Environment; Program Descriptions; Public Policy; *Scientific Research

ABSTRACT

This volume records the presentations made at the Symposium on Research Applied to National Needs. The three major problem areas of energy, the environment, and productivity serve as a focus for the papers. The 14 papers in the first section deal with energy programs; energy under the ocean; energy conversion and transmission systems; and geothermal, wind, and solar energy. The second section includes 10 papers covering threats to man and his environment, environmental programs and projects, disaster mitigation (earthquake engineering and fire research), mercury pollution, weather modification, and resourse management. The third section contains three policy addresses which discuss national research, energy policy, and environmental policy. Twelve papers in section 4 are concerned with productivity in the public and private sectors; the final section consists of one paper on research utilization. (DT)

ED 096154

○Energy
○Environment
○Productivity

Proceedings of the First Symposium on RANN: Research Applied to National Needs

Washington, D.C.
November 18-20, 1973

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National Science Foundation

Editor: Jay Holmes
Office of Intergovernmental Science
and Research Utilization

Library of Congress Catalog Card No. 74-600097

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402 - Price $3.40
Stock No. 3800-00177

FOREWORD

H. Guyford Stever
Director
National Science Foundation
Washington, D. C.

In recent years, the American people and their elected representatives have urged a strengthened effort to direct our Nation's scientific and engineering resources toward the solution of national problems.

One important focal point of this effort has been in the National Science Foundation. Its formal beginning was in December 1969 in a modest program with the title of Interdisciplinary Research Relevant to Problems of Our Society. In March 1971 its scope was increased substantially and its title was changed to Research Applied to National Needs (RANN).

During the first two and a half years of the RANN program, the research work has focused on three areas of national need: energy, the environment and productivity, both in the public and the private sectors of our society.

The direction of research toward the solution of problems has required new approaches and methods of operation in parts of the National Science Foundation. In RANN and other new programs, the institution and its staff have had to shift emphasis.

During the 20 years following the establishment of the Foundation in 1950, attention was concentrated largely on the support of basic research in universities, largely within the bounds of the established scholarly disciplines. Support of basic research, of course, continues to be the basic mission of the National Science Foundation. But in RANN we are broadening the base of our support to include industry, national laboratories and not-for-profit research organizations.

By the fall of 1973, we concluded that the program had reached a stage at which it would benefit from a major symposium before an audience of researchers and potential researchers, and users and potential users of the research results. More than 1,500 persons from industry, government and the university research communities responded to our invitation and attended this symposium, which was held November 18, 19 and 20 in Washington, D. C.

This volume, which records the presentations made at the RANN Symposium, provides examples of what can be achieved when the capabilities of scientists and engineers are directed toward national problems. It demonstrates again, we believe, that it is sound policy to use these resources in this fashion. What has happened and what is of great importance to this country is that in a period of relatively few years we have focused and begun to put to work in new ways and on new problems the powerful forces that have served us so well in the past.

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INTRODUCTION

PERSPECTIVE ON RESEARCH APPLIED TO NATIONAL NEEDS

Alfred J. Eggers, Jr.
Assistant Director for Research Applications
National Science Foundation
Washington, D. C.

It is a great pleasure to invite the attention of serious readers to the Proceedings of the first Symposium on the program of Research Applied to National Needs (RANN), of the National Science Foundation. This Symposium was held at the Sheraton-Park Hotel in Washington, D. C., on November 18, 19 and 20, 1973.

These Proceedings include all presentations made at the regular sessions of the Symposium and the text of the dinner address by the Director of the National Science Foundation, Dr. H. Guyford Stever, on the evening of the 19th. During the regular sessions there were also keynote addresses on major matters of national policy by Governor John A. Love, Director, Office of Energy Policy, and by Governor Russell W. Peterson, Chairman, Council on Environmental Policy.

All of the presentations were short and to the point, as was required for inclusion in two very busy days. For this volume, therefore, we encouraged speakers to add important supporting detail to their papers whenever they felt it to be warranted. Readers desiring still more detail can obtain it from the speakers or from technical reports available through the RANN Document Center.*

The appendices to the Proceedings include a list of the more than 1,500 persons who attended the Symposium, brief information on the dinner session and lists of films and exhibits shown at the Symposium.

RANN Objective

The RANN program is designed to focus U.S. scientific and technical resources on selected problems of national importance with the objective of contributing to their practical solution. This focus is in accord with the expressed concerns of the President, the Congress and, indeed, the American people for "harnessing the discoveries of science in the service of man."

An important purpose of RANN in this process is to shorten the lead time between the discoveries of science and their application in meeting the Nation's needs. Thus RANN provides a key bridge between the Foundation's basic research programs and the development and operations programs of the Federal mission agencies and other important elements of the user community, including state and local levels of government, and industry.

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*Office of Intergovernmental Science and Research Utilization, National Science Foundation, 1800 G Street, N.W., Washington, D. C. 20550.

Because of the key importance to RANN of the user community, the Intergovernmental Science and Research Utilization program (ISRU) operates as a complementary element to the RANN program. ISRU is the subject of a major Symposium presentation in this volume, with special attention to research utilization. The research utilization function will continue to be broadened and strengthened with all levels of government, and we will further increase our emphasis on the private industrial sector through collaborative efforts with appropriate associations such as the Industrial Research Institute.

The implementors of the RANN program are universities, industry and national laboratories. The pooling of their best talents to make up effective research teams is a driving force in these efforts. There is a powerful educational component in the problem-focused research supported by universities, where both faculty members and students serve on the project teams. Through these means, RANN enables the Nation both to benefit from the services of the best performers available and to strengthen the performer base.

To accomplish RANN's objectives in an orderly and efficient manner, RANN programs are constructed on the basis of phased project plans. In each phase, there are major milestones at which technical, environmental and socio-economic evaluations and assessments are made prior to initiating the subsequent phase. The first, Phase Zero, comprises advanced research and systems analysis. Phase One focuses on system definition and subsystem experiments. Phase Two carries through systems proof-of-concept experiments, which are undertaken to establish that the full technology base is available to enable the user community to move expeditiously to the design and development of operational systems.

The RANN program is now more than two and a half years old. It has been developed through an extensive process of planning, coordination and evaluation. This process focuses special attention on national needs and capabilities to meet them, as viewed by leaders of the scientific and technical communities, universities, industries, other Federal agencies, and state and local levels of government. This effort has included in-depth program reviews with the National Science Board, with major advisory committees of the Foundation, including especially the Research Applications Advisory Committee, with committees of the National Academies of Science and Engineering, including especially the Committee on Public Engineering Policy, and with industrial and professional societies.

One of the most recent products of this activity was a report included in the material provided to persons who attended the Symposium. The report, *Priorities for Research Applicable to National Needs*,[1] was published by the Committee on Public Engineering Policy of the National Academy of Engineering in November 1973. This report is the product of an intensive evaluation effort by nearly 100 experts in a wide spectrum of disciplines, ranging from the physical to the social sciences and representing the integrated views of both researchers and users of the research results in government, industry and universities. It has already importantly influenced the thrusts of new research efforts in the RANN program. This is especially true in the areas of the functioning of institutions to meet national needs and conservation and patterns of consumption of scarce natural resources including energy resources. I believe the reader will find it interesting to compare this report's recommendations on high-priority research needs with the progress and results of research reported during the course of this Symposium.

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[1] RANN Document No. NSF/RA/X-73-014.

Federal mission agencies have participated extensively in this planning and evaluation effort, through the RANN Coordinating Committee and its special panels and through other panels of the Federal Council on Science and Technology. These committees and panels have already provided important inputs to the shaping of the RANN programs of problem-focused research.

In deciding whether a specific problem of society should be addressed by RANN the following criteria are considered: importance of the problem, potential research payoff, leverage of science and technology on the problem, readiness of an effort, existence of suitable capabilities, need of Federal action, and appropriateness of Federal support by NSF-RANN. Affirmative decisions on RANN support may be given for problems that fall between or outside the areas of responsibility of other agencies, that span their areas of responsibility, that are related to meeting their longer-range or special requirements, and that are uniquely suited to solutions by strong interdisciplinary teams from universities, industry and national laboratories.

Through the application of these criteria in the comprehensive process of planning, coordination and evaluation, we have determined that the principal emphasis of RANN should be in the three major problem areas of energy, the environment and productivity in the public and private sectors of our society.

It should come as no surprise, therefore, to find these problem areas as key subjects of discussion at the first RANN Symposium.

Energy:

The national need to expand the Nation's energy resources is abundantly clear to all of us as illustrated by several circumstances. One is the adverse consequence that a growing dependence on fuel imports has on our foreign policy determinations and on our domestic well-being when these imports are curtailed. Another is the impact of current usage of conventional and nuclear fuels on our natural environment. A third circumstance is the dependence of our society on energy for sustained economic growth, transportation and other basic needs.

All of these considerations and more point to the urgent need of strengthened innovation and imagination in the search for alternative resources to meet the Nation's energy requirements, and to conserve its existing non-renewable resources. This volume includes the results of research on a number of these issues, beginning with considerations of overall energy systems and concluding with reviews of the potentials of solar energy to help meet national needs.

Environment:

The national need to expand the Nation's control over its environment is also abundantly clear to all of us. It is illustrated by the adverse consequences of threats to the man-made environment, including earthquakes and fires and, indeed, to man himself. In addition, there are the threats to the natural environment due to adverse weather conditions and the increasing release of trace contaminants, such as heavy metals, in this environment. Finally, there is the overall concern for increasing our ability to manage the environment effectively. This requires an improved understanding of the complexities of regional environmental systems coupled with the realization that local governmental structures do not usually possess a common boundary with the environmental problems they face. The results of research on a number of these environmental issues are also included in this volume.

Productivity:

The need to increase productivity in the public and private sectors of our national life is illustrated by the adverse consequences of inflation and an unfavorable balance of foreign trade. In the public civil sector, about 136 billion dollars is spent each year by state and local government in the purchase of goods and services. This level is increasing. It is important that research be conducted to determine the degree to which municipal performance can be improved through a better allocation of these funds. An essential aspect of this research is to examine new technologies and management concepts, which could improve city and state performance in the delivery of public services. In addition, there is need to improve the efficiency and effectiveness of those state and local government institutions that deliver public services. This volume includes the results of research on several of these issues and a major address on public sector productivity by Deputy Mayor Edward Hamilton of New York City.

In the case of private sector productivity, if economic growth is to be stimulated, the need to create new industries and to improve technology must be met. There are important opportunities to do this in the application of basic enzymology in selected industries, in the utilization of new magnetic processes for the concentration and improved recovery of minerals from indigenous ore, and in the increased use of automation in the manufacturing industries. This volume includes selected results of research in these problem areas and an address by John Diebold, who heads the Diebold Institute of Policy Studies, on the implications of new technologies.

Conclusion

In summary, let me emphasize that the primary purpose of the Symposium and of these Proceedings is to report some of the most significant results of the RANN program on important national problems. This research altogether has involved more than 1,200 individual projects throughout the United States, for which we have already obligated some $200 million in carrying them forward.

Many conferences and workshops have of course been held previously to report the results of research to the immediate user communities in the various areas of the RANN program. Examples have ranged all the way from solar and geothermal energy through environmental land use planning, the use of thermal batteries and the large-scale removal of solid waste from major cities. But this was the first Symposium that covered all the major inter-related issues addressed by RANN. The papers in this volume give special attention not only to the viewpoint of the researchers but also to the users of the research results.

This fact serves to emphasize the high importance placed in the RANN program both on good research and effective research utilization. We all know that the effective mix of these efforts is one of the great challenges to achieving high payoff from problem-focused research. For this reason, not only the speakers but also the audience comprised both researchers and users of research on national needs.

We all recognize, too, that Research Applied to National Needs is a highly interdisciplinary endeavor involving technologists, environmentalists and social scientists working as teams to serve the needs of decision makers at all levels of the government, industry, business and labor communities.

If this joining of forces is to be successful in meeting our Nation's challenges of today and in moving our Nation effectively into the future, then we must learn to pool our resources in a common effort and with a common language that we can all understand. This Symposium and these Proceedings are in a very real sense an experiment in such collective understanding and action. The author of each presentation has attempted to address all readers, whether their special responsibility is in the area of energy, the environment or productivity. I sincerely hope also that readers of the Proceedings who are primarily interested in one problem area will give careful attention to the presentations in the other problem areas. I say this because I am certain that in our time, and for the foreseeable future, *energy*, the *environment* and *productivity* are national issues that are closely interdependent. No one of these issues will be dealt with effectively without due understanding and consideration of the other two.

ENERGY

THE RANN ENERGY PROGRAM

Richard Green
Deputy Assistant Director for
Program Management, Research Applications
National Science Foundation
Washington, D. C.

The RANN Energy Program is the largest in the total RANN Program from a dollar viewpoint. It supports research and technology development in areas which lead to the implementation and utilization of new energy concepts.

Objectives and Program Elements

The major objectives of the program are to analyze the intermediate and long-range needs for energy and explore the various strategies for meeting them, to identify and investigate technologies that have the potential for significant impact on the energy situation, and assess the environmental, social and economic impacts of energy production, distribution and use, to minimize detrimental effects.

There are several major elements of the RANN Energy Program, each of which will be addressed today.

They are:

Energy Systems, where we analyze and synthesize alternative means of meeting U.S. energy requirements.

Energy Conservation, the analysis and development of alternative means to save energy in an environmentally acceptable way.

Technology Assessment, the determination of the impact of introducing a new, or modifying an existing, technology.

Energy Resources, the development of methods for effectively utilizing conventional energy resources (e.g., coal).

Energy Conversion and Storage—these involve new technologies to convert energy to a form practical for transmission and use.

Energy and Fuel Transportation, the transportation of energy from the source of production to the site of consumption by using novel power transmission techniques.

Geothermal Energy—to assess and prove its potential as a resource base.

Solar Energy—to develop the research base needed for the terrestrial applications of solar energy.

Our research results *per se* mean little if they are not utilized. To this end we maintain close couplings with user agencies and other organizations. For example, our advanced Coal Research Program is closely coordinated with the Office of Coal Research in the Department of the Interior; our Solar Energy Program, for the heating and cooling of buildings, with the Department of Housing and Urban Development, the National Bureau of Standards in the Department of Commerce; the Systems Program, with the Federal Power Commission and the White House Office of Energy Policy, and the Energy and Fuel Transmission Program for the electric utilities is working closely with the Electric Power Research Institute and the Atomic Energy Commission.

The presentations that follow cover significant areas of the RANN Energy Research and Technology Program. The systems approach to national energy production and consumption will be addressed by Mr. Wetmore. Dr. Carlsmith will cover energy conservation research. Dr. White will report on a technology assessment of offshore oil, and there will be an evaluation of that assessment by Mr. Radlinski. Dr. Squires will present improved techniques for gasifying coal. Mr. Compton will describe an example of energy conversion and storage technology, the sodium sulfur battery. Dr. Peschon will review the status of knowledge of energy transmission systems. Drs. Kuwada and Ramey will present an overview of the challenge of geothermal energy. Then the attention will turn to solar energy. Mr. Thomas will report on wind energy conversion. Dr. Eckert and Mr. Schmidt will review thermal conversion of solar energy. Dr. Löf and Dr. Böer will describe the use of solar energy for heating and cooling of buildings. Finally, there will be status reports on work on the problems of commercialization of solar heating and cooling of buildings, from Messrs. Farnham, Stewart and Petrou.

ENERGY SYSTEMS

William H. Wetmore, Director
Office of Systems Integration and Analysis
National Science Foundation
Washington, D. C.

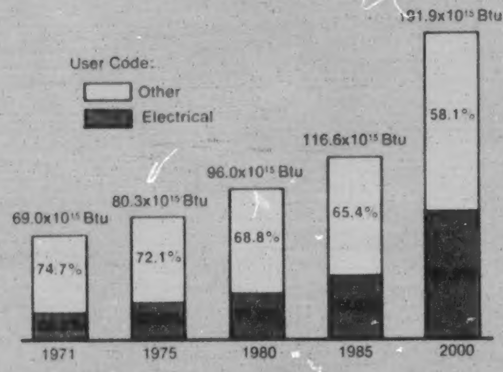
Energy—in all its forms—is essential to the health and growth of this nation. Energy touches every facet of our lives. It has brought us great wealth and a strong industrial base. It has produced a great change in our society and has given us one of the world's highest standards of living.

However, as we are all becoming fully aware, the demands for energy are rapidly outstripping available supplies. Our current supply problems may become even greater in the future.

In Figure 1, a projection of the nation's energy consumption, we see two major facts:

- **The demand is projected to increase by 50 per cent every decade.**
- **A major shift in emphasis indicates that power generation may well become the largest energy consumer (42 per cent). We will need more power plants—in contrast to energy for cars, homes—and that can have a major impact in our national energy planning.**

Figure 1—**Estimated Total Energy Use and Energy for Generating Electricity 1971-2000**



Every day—in newspapers, television, the actions of our governments and those abroad—we see more evidence of the magnitude and seriousness of the energy problem.

Massive efforts are being considered within the Congress and the Executive Branch to solve it. And one step in its solution is to scope and understand the problem and all of its ramifications. That is the beginning—leading to the development of sound programs.

In defining the scope of the problem, we all know we are not dealing with just a question of supply and demand. We know that many related factors must be considered—such as the environment, the relationship between energy and industrial productivity, the impact of energy on employment, the policies and regulations relating to energy. These technical, environmental, social, economic, legal and regulatory issues require that we address these problems from a total systems viewpoint.

A Major Problem—a Major Challenge

I would like to outline the way in which the RANN energy systems program addresses this national issue. In our program, we look at the resources, the conversion of the resources and the end uses of that energy to determine the most efficient means of utilizing our national energy resource base.

A major purpose of the RANN energy systems program is to identify the energy research and technology development opportunities.

We also are improving the base of information and data essential for energy planning. We are developing national and regional energy models to provide decision makers with a better understanding of the consequences of the options available to them. Finally, we are examining the impact of regulatory activities in the energy field.

Now let me describe the major elements of the program to show how it is structured, and to cover major current and planned activities in certain areas.

In resource analysis, we are examining both our current resources—oil, coal, gas, nuclear—as well as advanced energy resources—oil shale, tar sands, solar, geothermal, hydrogen, etc. For example, we have a major project to develop improved techniques for coal gasification—and Dr. Squires reports on that in another paper in these proceedings.

Within RANN we have programs assessing the resource of the outer continental shelf as it applies to our near-term energy requirements. Dr. Irvin White describes that research.

In solar energy, there are several major areas of application. The most prominent are solar heating and cooling of buildings, and electric power generation. Research reports from industry and universities describe the applied research RANN is sponsoring in these areas.

Another example is in geothermal energy. A paper by Drs. Kuwada and Ramey discusses this subject. Much is known about the potential that oil shale offers. Those projected resources are equivalent to 200 years of oil if consumed at the current rate. Oil shale requires a major examination of the issues relating to technology, the environment, economics, societal acceptance and other facets.

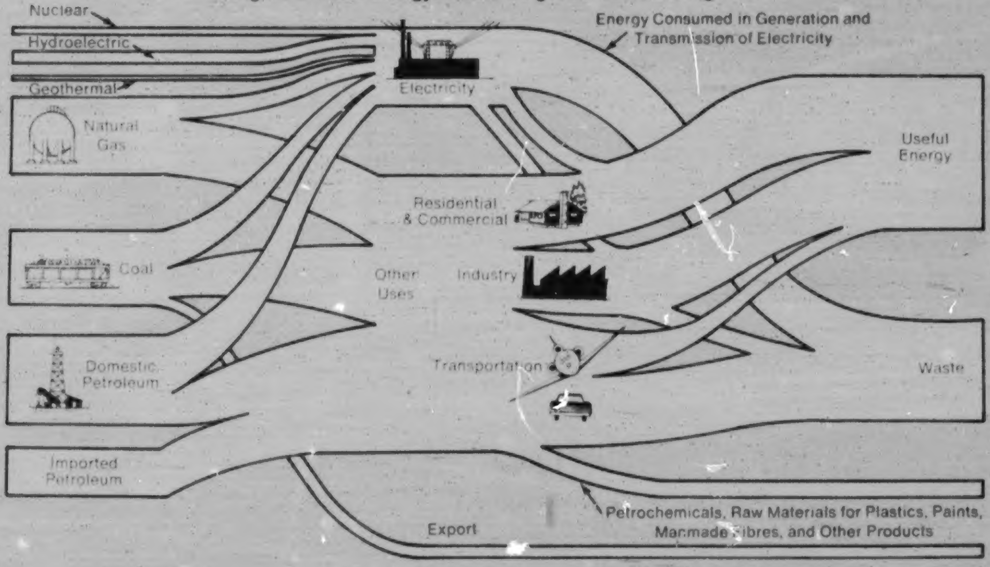
These are examples of current and ongoing RANN research and hard technology programs. In addition we are conducting studies of various resources and combinations of resources such as solar energy, geothermal energy, oil shale, nuclear and coal to determine their capability to meet our natural resource requirements. We also are assessing coal technology and developing recommendations regarding the most productive and beneficial coal research programs. We are evaluating conservation practices, environmental constraints and their impact on energy resources. The list could go on and on.

In conversion systems analysis, our activities encompass power generation, transmission and distribution, and energy use in the residential, commercial and industrial areas as well as transportation.

Opportunities for Conservation

There is an obvious and close interaction between supply and demand as portrayed in Figure 2, and higher efficiencies mean less energy consumption. There is a further close interrelationship between higher efficiencies in all conversion systems, conservation and the environment. Increased efficiencies lead to lower waste

Figure 2—**U.S. Energy: where we get it and where it goes**


Nuclear
Hydroelectric
Geothermal
Natural Gas
Coal
Domestic Petroleum
Imported Petroleum
Electricity
Energy Consumed in Generation and Transmission of Electricity
Residential & Commercial
Other Uses
Industry
Transportation
Useful Energy
Waste
Export
Petrochemicals, Raw Materials for Plastics, Paints, Manmade Fibres, and Other Products

heat and lower thermal pollution. Improvements in conservation have an impact on the demand for resources and the need for new power generating facilities.

The residential and commercial areas now account for 23 per cent of the total energy consumption—in space heating, water heating, air conditioning, refrigeration, etc. We are working in public and private housing and with school boards. We have projects treating the unique case of the mobile home, which represents one of every five homes built in recent years.

In residential energy consumption, studies showed that annual energy consumption can be reduced as much as 40 per cent without affecting lifestyle and at an increase of only 3 per cent in the initial cost of the house.

Specific home units such as air conditioners also have been examined. Increasing the average efficiency by 50 per cent (not unrealistic) would result in a reduction in energy consumption for air conditioners alone of 16 billion kilowatt hours —the equivalent of about six good-sized power plants (600 megawatts electric).

The industrial sector is critical because it represents 28 per cent of the total national consumption. In fact, six industry groups in manufacturing—including food, petroleum and coal products, and primary metals—account for 67 per cent of all fuels and electric energy consumed by manufacturing industries.

We have studies in selected industries to determine improvements that will lead to the more efficient use of energy. We also are planning to examine this area to determine means of increasing industrial productivity without major increases in the consumption of energy.

Another major task affecting the industrial sector carried out at the Oak Ridge National Laboratory deals with the recycling of the five more commonly used metals—aluminum, iron, copper, titanium, and magnesium. Recycling aluminum requires less than 5 per cent of the energy required initially to produce it. In general, recycling provides more metal with less energy consumption. That we know—we have pointed out an opportunity. With other agencies, we will find ways to implement what we have learned about the value of recycling.

Food is a key industry and one of obvious importance to the consumer. Because we spend one dollar out of every five for food, and because food-related activities consume more than 12 per cent of our energy, we plan to expand our current efforts in this area.

Transportation is another vital field, accounting for 25 per cent of the total energy consumption and projected to double every 20 years. The automobile consumes more than half of that energy. Studies have shown that conservation in the transportation sector could reduce energy consumption by one-fourth.

The examination of passenger and freight transport modes provides some interesting insights. Since 1950, the energy consumption per passenger mile has increased for all modes of transportation except for railroads. The overall improvement in rail transportation was the result of a shift from steam to diesel engines.

Aircraft fuel consumption rates increased because of increased speed. On an overall basis, passenger transport fuel consumption increased considerably because of the shift from trains and ships to aircraft and autos. This data has led RANN to focus its studies in the transportation sector on the automobile and, specifically, its highly inefficient engine. Considering replacement of the internal combustion engine, certain conclusions from our studies stand out:

- **The replacement of the present automobile engine with a new one based on advanced engine concepts would lead to major reductions in pollution.**
- **A switch to compact cars will have major socio-economic effects—especially on the auto and associated industries. But that switch will materially benefit our environment and will reduce our use of natural resources.**

Keep in mind that we are trying to minimize waste in both energy and materials. And so, this whole energy system needs to be examined in a closed-loop fashion. A key consideration in any possible decision to switch to compact cars is the impact of that decision on industries and employment. If such a decision is made, there must be an orderly transition.

In energy conservation, we have with the State of California developed methods for estimating energy demands for a variety of alternative futures. We have applied these methods to evaluating the effect on energy use patterns and have examined the benefits and costs for conserving energy.

Building on that experience, we are now planning a coordinated effort on a national scale working in the Northwest, the Midwest, New England and the South Central States. We hope to develop a pilot approach that on a monthly or seasonal basis will provide data with which states can develop policies and strategies on issues of fuel regulation. Then they can evaluate the relative consequences of those policies. For example, if a state has *X* gallons of fuel, where should it go to be used in the best interest of the citizens of the state? Should it go to schools? Homes? Hospitals? Industry? Who gets it?

In all areas of supply and demand, we have supported the development of models that can be used to analyze the consequences of alternative policies, alternative costs, new technologies.

Examples in this area are:

- **Power system analysis (Massachusetts Institute of Technology) to examine trade-offs among economics, environment and reliability in regional power systems. These results are now being applied to the New York area.**
- **Energy data bank (MITRE Corp.) to develop a national energy accounting process to trace the flow of energy through the economy from mining and production to utilization.**

In policy and regulation, our projects are designed to investigate methods of regulation, pricing policies and the effects of subsidies.

In our energy systems program, we maintain close relationships with the Office of Energy Policy and with many Federal agencies (e.g., Department of Housing and Urban Development, Department of Transportation, Department of the Interior, Atomic Energy Commission, Council on Environmental Quality, Federal Power Commission). Specifically, we are about to initiate, at the request of the Office of Energy Policy, a study of the interchangeability of oil and gas in residential and industrial uses. In addition, we are working closely with the Council on Environmental Quality on energy impact matters. Further, we are working with the Department of Urban Development on studies of single-family residences in the Washington-Baltimore area. These and other examples underscore the stress RANN places, first, on getting research utilized, and second, on maintaining close relationships with other Federal agencies.

We all have concern for finding ways of making more efficient use of our nation's energy resources.

We in RANN's Energy Systems program are committed to finding viable solutions to this complex, challenging problem. However, the measure of success depends in large part on the participation and contribution of all our citizens.

ENERGY CONSERVATION PROGRAMS

Roger S. Carlsmith *
Associate Director
ORNL-NSF Environmental Program
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Oak Ridge, Tennessee

The need for energy conservation is well recognized. Everyone understands we must achieve greater efficiency in the use of our energy resources.

NSF/RANN recognized this need and has supported a program of research on energy conservation at the Oak Ridge National Laboratory over the last three years.

Program Highlights

Four areas of work are typical of the kinds of efforts going on. These represent continuing activities at the Oak Ridge National Laboratory. The areas are:

- **Energy Conservation in Transportation.**
- **Energy Conservation in the Residential Sector.**
- **Studies of Demand for Electricity.**
- **Energy Information.**

The goals of our transportation-related work are to understand historical and present energy use patterns for passenger and freight transport, to evaluate the energy implications of various transportation alternatives and to examine the effects of alternative policy measures designed to save energy.

Transportation Patterns

We have analyzed energy use patterns from 1950 to 1970 in terms of changes in traffic levels, shifts in modal mix and changes in modal efficiency for each mode.

During this period, energy use for passenger travel rose 86 per cent. There was a 46 per cent increase in per-capita travel, a 21 per cent increase in population and an 18 per cent increase in the amount of energy used per passenger mile. There was a steady shift toward the use of energy-intensive modes of travel and a steady increase of energy intensiveness within those modes.

We also evaluated total energy requirements for automobiles. In addition to the gasoline used directly, total energy includes the energy required to build highways, refine petroleum, make cars, etc. The total energy requirements of a car exceed its direct gas consumption by 70 per cent.

Continuing studies explore the direct and indirect effects of various possible measures for reducing the use of energy in transportation. These would include various taxes, incentives and regulations designed to encourage the use of the more efficient modes of travel.

A number of implementation activities have been undertaken related to this work. These have included publication of research results in both professional and popular journals. We have provided testimony on energy conservation to the U.S. House Subcommittee on Science, Research and Development, the Senate Interior Committee, the House Subcommittee on Energy and the Subcommittee on Conservation and Natural Resources. In addition, testimony has been given to the Tennessee House Committee on Energy Sources.

Results of our studies have been used by Federal agencies in their energy-related work. Published examples include *The Potential for Energy Conservation* by the Office of Emergency Preparedness, *Energy Conservation Strategies* by the Environmental Protection Agency and *Transportation Energy Conservation Options* by the Department of Transportation.

Residential Conservation

Our second area of research, energy conservation in residential use, has three goals: to determine how energy is used in residences, to determine where energy inefficiencies may exist and to investigate the technological and economic feasibility of reducing those inefficiencies.

For example, thermal insulation requirements included in current Federal Housing Administration (FHA) minimum property standards for residences fall considerably below the optimum economic level. In other words, the home owner could save both energy and money by greater use of insulation. In addition, a large number of old and new homes do not even meet those minimum standards.

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* Dr. Carlsmith presented the paper that was to have been given by Dr. John H. Gibbons, Director, Office of Energy Conservation, Department of the Interior. Dr. Gibbons was called to a White House meeting on the energy crisis.

We have found that heat pumps offer an opportunity for electrical space heating with considerably less energy use than the much more common resistance heating. The energy-use reduction would be more than a factor of 2 as far north as Philadelphia and would still be a factor of 1.6 as far north as Minneapolis.

The efficiencies of window air conditioners being sold commercially vary by a factor of 2.5. The additional first cost of the more efficient models is recoverable through lowered power bills in much of the country, particularly in those areas having high energy consumption for air conditioning. Energy for air conditioning can of course also be greatly reduced by higher thermostat settings—10 per cent for each degree.

Increasing the insulation thickness on electric water heaters—from the usual 2 to 5 inches—would save about 350 kilowatt hours a year per heater and would provide a small net monetary saving to the home owner. Nationwide application would save approximately the output of a one-million kilowatt power plant.

Our findings on the value of added insulation have been given to representatives of the Architecture and Engineering Division of the Department of Housing and Urban Development (which is responsible for FHA minimum property standards), to the Council on Environmental Quality and to House and Senate committees. Findings from the insulation, air conditioning and heat pump studies and possible ways these might be implemented were given to the Tennessee Valley Authority. The TVA has issued a folder portraying the energy and money savings available through better insulation.

Demand

A third area of activity considered the demand for electricity. The main objective of this effort was to provide information and methods to enhance understanding of the nature of electrical demand growth. We have developed electricity demand models for industry, residences, and commercial buildings and have disseminated the results widely. We are now developing similar models, more fully disaggregated to regional electrical demand.

Historically, demand projections have been made almost exclusively from trend extrapolations. In recent years, important growth factors—particularly the prices of electricity—have been departing from past trends. Thus forecasts made using conventional methods will become less reliable.

We find the demand for electricity is price-elastic. When we make reasonable assumptions about future prices, population, incomes, prices of competing energy forms and appliance prices, we obtain forecasts of future electricity demand appreciably lower than by some other well known projections. I should add a word of caution, however. We also find that there is a time delay of 6-10 years in the response to price changes. Thus one cannot expect electricity price rises to be a near-term solution to the problem of supply shortages.

In another area, we have calculated the total energy expenditures for growing, processing transporting, selling and consuming food. These activities use 12 per cent of U.S. energy. An average of 6.4 British thermal units (Btu) of primary energy is needed per Btu of food energy used by the consumer.

In energy use in the industrial sector, we determined the energy consumption for recovery of a number of important metals from virgin ore. For comparison, we also obtained the energy needs when the same metals are obtained by recycling. These vary from metal to metal. At one extreme, the recycle of magnesium would take 1-2 per cent as much energy as recovery from seawater, while recycle of iron would take 45 per cent as much energy as processing ore.

Information

A final area of study deals with basic energy information. With rapid proliferation of information in this field new storage and retrieval systems are needed.

We are building an extensive computerized system at Oak Ridge to deal with information on energy, the environment and society. One of the outputs from this system is the monthly journal *NSF/RANN Energy Abstracts*.

Others are numerous searches and special-purposes bibliographies, which we prepare to meet the needs of Federal and state agencies.

We believe that the RANN research on energy conservation, both at Oak Ridge and elsewhere, is having an effect. Important areas have been identified for more efficient energy use. The research results, in turn, have led to better public awareness and to new administrative and legislative initiatives at both the Federal and state levels. Continuing interaction on all of these levels is important to solving our critical energy problems.

ENERGY UNDER THE OCEANS

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The purpose of this paper is to report on a technology assessment of oil and gas operations on the U.S. Outer Continental Shelf (OCS). This assessment, sponsored by the RANN Program of the National Science Foundation, was conducted over a 20-month period by an eight-man interdisciplinary team in the Science and Public Policy Program at the University of Oklahoma. A report of the assessment, *Energy Under the Oceans*,[1] has been published by the University of Oklahoma Press.

Background

Petroleum accounts for almost 70 per cent of all energy consumed in the United States. Approximately 70 to 80 per cent of this is produced domestically. Domestic production has been decreasing, and there is some question as to whether we can continue to produce this large a percentage of the oil and gas that we consume.

Over the short run, as Figure 1 shows, there are only four sources for increasing domestic production in the amounts required:

- **The Outer Continental Shelf (OCS).**
- **State lands offshore.**
- **On land in the lower 48 states.**
- **The North Slope of Alaska.**

As indicated in Figure 1, only the Alaskan North Slope and the OCS have a potential for significantly increasing domestic U.S. production.

Actually, imports—as shown in Figure 2 have recently accounted for around a third of the petroleum used in this country. It is clear that in the near future, the United States will need to continue to import oil and gas. If imports are not available, oil and gas supplies will not be adequate to meet present demand. This, of course, gives added impetus to move rapidly in developing oil and gas resources in Alaska and on the OCS. Without significant reduction in demand, producing oil and gas from these two sources will not

Figure 1—**Four Sources of Domestic Production**

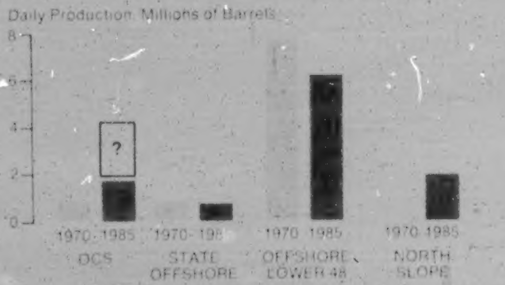
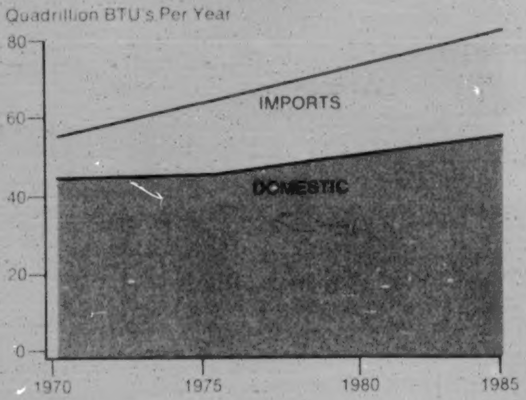


Figure 2—**Estimated U.S. Oil & Gas Consumption**



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[1] Don E. Kash, Irvin L. White, Karl H. Bergey, Michael A. Chartock, Michael D. Devine, R. Leon Leonard, Stephen N. Salomon, and Harold W. Young; *Energy Under the Oceans: A Technology Assessment of Outer Continental Shelf Oil and Gas Operations* (Norman, Oklahoma: University of Oklahoma Press, 1973); and *Energy Under the Oceans: A Summary Report of a Technology Assessment of OCS Oil and Gas Operations* (Norman, Oklahoma: University of Oklahoma Press, 1973) (RANN Documents NSF/RA/X-73-001 and NSF/RA/X-73-002 respectively).

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eliminate the need for imports; however, production in these areas can lessen the shortage that will occur when imports are cut off.

In moving to develop domestic resources to reduce U.S. dependence on foreign energy sources, those making the decisions need to be informed about the costs and benefits associated with developing each of the available domestic alternatives. These policy makers must seek to balance demands for protecting the environment against demands for more energy.

The Study

This really sets the stage for what the Oklahoma assessment was all about. Technology assessment is an attempt systematically to identify, analyze, and evaluate the potential environmental, legal/political, and other social impacts of a technology. In this study our objective was to analyze the broad social implications of what developing OCS oil and gas resources would mean.

Energy policy in the United States now is being made in a highly-charged political environment. A concern for environmental quality generally and for the environmental impact of OCS development specifically have significantly changed the social context within which energy policy is being made.

The Santa Barbara oil spill was an important symbolic event. Before Santa Barbara, management of the OCS was very largely an administrative process. The government regulator and the offshore petroleum industry generally shared common goals.

A major effect of Santa Barbara and other OCS accidents has been to change the closed character of that policy system. New participants are demanding a right to be heard and they are demanding a more stringent regulatory system, strictly enforced.

The process no longer is one that can be accurately characterized as primarily administrative. It is now overtly political. Policy makers must now deal with conflicting demands. It is in this context that policy makers are having to make choices about the OCS, often without having much knowledge about this area and the broad social implications of developing it.

Focusing on the future, we had four major objectives for our assessment, to:

- **Assess a broad range of social impacts associated with the development of OCS oil and gas resources.**
- **Contribute to rational policy-making for the OCS.**
- **Contribute to the formulation of a social-technological system for the development of OCS oil and gas resources responsive to broad social concerns.**
- **Make specific recommendations for changes in government policy and administration, industry management, and technologies which will contribute to optimal resource development on the OCS.**

We began our study by attempting to learn about the physical technologies, the hardware being used on the OCS. We acquired this knowledge by a number of means: A petroleum engineer spent a year with our group; we made site visits, and we maintained extensive contact with companies and individuals within the petroleum industry, government and environmental groups.

We also addressed, sequentially and systematically, four basic questions:

- **What are the issues, technological and otherwise?**
- **What factors contribute to these issues?**
- **What appear to be alternative solutions?**
- **What are the costs and benefits associated with each of these?**

Also, at several stages during our study we produced preliminary reports that were reviewed as widely as was feasible—by persons from industry, government, environmental interest groups, and by academics. And we always evaluated and responded to the critiques we received.

We also made an effort throughout the study to stay in touch with the potential users of our results. We did not want to produce a study which would be just an academic exercise relegated to the role of dust-catcher in someone's bookcase.

At the outset, the assessment was designed to focus on existing and anticipated physical technologies and technological alternatives for finding, developing, producing, and transporting oil and gas. As the study progressed, it became clear that this accepted conception of technology as-

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Vary Coates, *Technology and Public Policy: The Process of Technology Assessment in the Federal Government, Summary Report* (Washington: Program of Policy Studies in Science and Technology, George Washington University, July, 1972), (RANN Document NSF/RA/X-72-003), p. 1.

sessment was inappropriate for this particular problem area. Technologies used on the OCS proved to be relatively stable and technological alternatives limited. This turned out to be an area where technological breakthroughs have not occurred. Technological change has been and will continue to be gradual unless there are major new initiatives by industry, government or both. How technologies are managed and regulated, what we came to call the social technologies, proved to be the critical element in this problem area. As already noted, this is due primarily to three major factors: (1) changes in the social context within which OCS policies are made and administered; (2) changes requiring that attention be paid to new concerns, especially for environmental quality and safety, and (3) changes requiring that participation be expanded to include others in addition to industry and government, particularly environmental and consumer interest groups.

Once it became clear that most of the changes required to provide for optimal development involve behavior and relationships of responsible persons in industry and government rather than hardware, the focus of the assessment was shifted. Although physical technologies were still to be assessed, the major effort was redirected to become an assessment of social technologies associated with the present and future development of OCS oil and gas resources.

Specific policy issues related to particular negative or undesirable impacts were identified, alternative responses were defined and analyzed, and recommendations to achieve desirable changes were formulated. Limited quantitative data are available for defining certain undesirable impacts, such as blowouts during drilling, for example. However, the effect of most changes in rules, standards, and procedures cannot be measured in quantitative terms. As a consequence, the standards employed in the study were for the most part procedural. That is, the assessment was in terms of whether present or proposed rules, standards, management practices, and changes in decision-making and administrative processes, could be expected to reduce or eliminate undesirable impacts.

In this report, our findings are summarized beginning with our assessment of specific physical technologies and moving to our recommendations for an overall management plan for the OCS.

Issues and Recommendations

Although the best physical technologies used on the OCS are generally adequate to permit oil and gas resources to be found, developed, produced, and transported safely with minimal adverse social impacts, our assessment identified a number of technological weaknesses which can be divided into four categories:

- **Some technologies are inadequate.**
- **Some are only marginally adequate and need to be improved.**
- **Some technologies now available are not being used as widely as they should be.**
- **Some technological gaps need to be filled.**

These weaknesses are described in detail in *Energy Under the Oceans*. An example will suffice for purposes of this summary.

Almost everyone who studies OCS technologies identifies downhole safety devices, or storm chokes as they are commonly called, as being a weak point in production systems. These devices are intended to shut down a well automatically when an accident occurs.

Two alternatives for dealing with this problem are to make the storm choke more reliable or to replace it with another valve.

Actually, an alternative valve actuated from the surface is now available and is being required in almost all new wells. But there are a large number of old wells on the OCS. This seems to call for developing a technological capability for replacing velocity-actuated valves in old wells with new surface-actuated valves that would still permit production at an economic rate.

It is important that this example of a technological weakness be kept in perspective. In fact, we found that most such weaknesses could be corrected by employing state-of-the-art engineering capabilities.

Having identified a number of technological weaknesses, we asked why they existed. The answer is tied to the way OCS policy was made and administered before Santa Barbara and to the closed character of the petroleum industry as an engineering community. Until very recently, standards used for determining the adequacy of OCS technologies have been based largely on industry's judgment of what was economically feasible. Before events such as the Santa Barbara blowout attracted widespread public attention, continuous participation in policy-making and administration for OCS development had been pretty much limited to government and industry. The rules and regulations established by responsible government agencies had usually stated objectives rather than detailed specifications and standards. The most detailed rules—OCS orders issued for each U.S. Geological Survey Area—had been and are the product of an institutionalized process of government-industry cooperation. Perhaps as a consequence, government regulation had tended to be heavily dependent upon industry's engineering and operational expertise when establishing OCS regulations.

In short, as noted earlier, the system of managing and controlling OCS operations had been effectively closed to outside influences on a continuing basis. When it was subjected to close public scrutiny following Santa Barbara, some of the disadvantages of this closed decision-making system were identified. Specific disadvantages include:

1. A tendency to develop technologies in a step-by-step, component-by-component way. In other words, the development of technological systems has not been emphasized.
2. A tendency to do things as they have always been done before—to the point of carrying a land-based mentality offshore.
3. Little appreciation or use of human factors design criteria despite the fact that humans are singled out as the cause of most accidents.
4. Until very recently, no industry-wide system for systematically reporting and analyzing data on accident and equipment failures, thereby limiting what could be learned from experiences.
5. Inadequate specifications and performance standards.
6. Quality control was generally limited to saying "if it breaks, bring it back and we will give you another one." The quality control programs now being established are based on a study done for the U.S. Geological Survey by a NASA team.
7. Personnel training and testing have been weak. Training programs have not been based on available knowledge concerning learning and human behavior; and there is no government or industry mechanism for evaluating the effectiveness of the programs or the performance of trainees.

As indicated earlier, we also looked at the social system of managing and controlling OCS development. Again the approach was to identify what appeared to be major problem areas and attempt to determine why they were problems. We were able to group these into four major categories:

1. Issues that arise in connection with the availability of information and data.
2. Concerns for environmental quality.
3. Problems of government management.
4. Jurisdictional problems—between agencies within the federal government, between the federal government and states, and international.

Take the background data issue, for example. It is really striking that both those who favor and those who oppose development of OCS oil and gas resources seem to believe that their case would be made if we had complete knowledge of the effects of oil on the marine environment.

Opponents believe that more knowledge will show that the effects of development are so socially undesirable that development would be stopped. Proponents, on the other hand, believe that more knowledge will show that there are *no* significant undesirable effects.

But the important policy point concerning this issue is that acquiring anything like complete data will be extremely long term and expensive. Decision makers simply are not going to have complete data upon which to base their decisions. They will have to operate with selected bits of data and a high degree of uncertainty. The policy need, therefore, is to identify the most immediate needs and to set research priorities so that these needs can be met.

This issue together with those concerning environmental quality, government management, and jurisdiction are discussed at length in *Energy Under the Oceans*. In addition to an analysis of the issues themselves, the study identified and assessed policy alternatives. These analyses are the basis for recommendations aimed at improving the quality of OCS development.

We propose an extensive list of recommendations that range from a focus on a specific piece of equipment to problems that arise because there is no fixed outer limit to national jurisdiction over adjacent submerged lands. If adopted, individual recommendations are intended to improve OCS operations incrementally. Collectively the recommendations constitute a "Plan for OCS Development" and are intended to provide for a flexible policy-making and administering system which would promote optimal oil and gas development. In formulating this plan, it is assumed that:

- **Policy must be open and formalized at every level within government—and that this requires substantial lead time.**
- **The burden of insuring optimal OCS development falls on persons in government and industry who oversee and conduct OCS operations.**
- **The decision to develop these resources can not be delayed until complete knowledge concerning social impacts is available. Indeed, a major requirement for optimal OCS development is a management system that can accommodate conflicting data and interpretations as well as conflicting goals.**

In our view, the system for managing and administering OCS oil and gas operations should do these things:

1. Effectively coordinate long-range planning and policy-making.
2. Broaden participation in OCS policy-making and administration.
3. Build greater expertise within government to enhance the regulatory capabilities of responsible agencies.
4. Provide more extensive, publicly disclosable information and data for making government management decisions.
5. Move toward greater centralization of responsibility and authority.
6. Clarify jurisdictional gaps and ambiguities.
7. Specify the portion of the nation's energy demand to be satisfied by OCS gas.

While not a complete overhaul, the sum of our recommendations does represent a major modification in the management of OCS operations. A substantially-expanded role for the environmental impact statement process is central to our "Plan for OCS Development." We believe this process will provide a vehicle for formulating regional coastal zone development and land use plans. These should integrate energy, multiple use, and environmental concerns.

We also are relying on this expanded impact statement process to provide the lead time, the additional information, and the early and broad public access to decision-making which will be required.

Seven Steps of Implementation

We recommend that this process be instituted in seven steps:

- **A 10-year development schedule should be published for OCS oil and gas resources.**
- **A programmatic impact statement should be prepared for each of the regions included in the ten-year schedule.**
- **The present five-year lease schedule should be modified to identify areas on the schedule by coordinates.**
- **When an area is included on the five-year lease schedule, data should be collected for the lease sale impact statement. These data should be made available to the public.**
- **When an area is included on the five-year schedule, the National Oceanic and Atmospheric Administration should initiate continuous hydrocarbon baseline and toxicity studies as a base against which to measure future impacts.**
- **The draft lease sale impact statement should be made publicly available at least 15 months prior to public hearings in order to provide time for public response.**
- **Each draft lease sale impact statement should be reviewed by an *ad hoc* committee appointed by the Committee on Environmental Quality. This committee's membership should be broadly constituted.**

These recommendations summarize our proposals for modifying the overall policy-making system. We emphasize that our objective in using the impact statement process to force planning is not an adequate substitute for a land-use planning system. We choose it because, in the absence of such a system, the impact statement process offers a flexible means to provide for safe and intelligent OCS oil and gas development.

Following these more general recommendations are several aimed at concentrating responsibility for detailed management in the Geological Survey. This would result in a transfer of several activities from other agencies.

We also recommend expanding the Survey's responsibilities and significantly increasing its funding. Expanding the Survey's capability seems to us to be a necessary condition for safe operations.

Finally, we specifically address the management of hardware. We recommend that:

- **USGS establish more detailed performance standards for hardware.**
- **USGS undertake an expanded program of hardware R&D and testing to back up its regulatory process.**
- **USGS and industry undertake efforts to improve the training of offshore personnel.**
- **Industry focus specific attention on the use of human factors criteria in equipment design.**

There are numerous others.

Conclusion

We believe most OCS resources can be safely developed at an acceptable level of risk. However, we add two important caveats: (1) There may be specific tracts, areas or both that can not be developed safely or where the risks are unacceptable because of unique conditions. (2) In the long run, safe and environmentally acceptable development depends on the quality and sensitivity of the system of managing and controlling OCS development.

As indicated earlier, we made it a point to maintain contact with the potential users of our study's results. We also have been active in promoting utilization of our results. Publication of our report was announced at a one-day symposium held at the National Academy of Sciences. Both the report and a summary volume have been widely distributed in industry and government. We briefed Congressional staff members in a session organized by the Congressional Research Service. Our report was a reference document for the Council on Environmental Quality's national hearings on developing Continental Shelf oil and gas resources on the East Coast and in the Gulf of Alaska. We participated in those hearings. Together with the National Academy of Engineering report on the OCS, our study was a basic document for a two-day Resources for the Future symposium on OCS technologies. We have made a large number of presentations to a variety of groups.

All of these have helped or will help to make the results of this assessment known to persons who are interested in or have responsibilities in connection with OCS oil and gas development. However, one of the most important factors in insuring that the report will be used has been our continuing communication with the Geological Survey.

In the following paper the deputy director of the Survey indicates some of the ways in which the Oklahoma study has benefited the Survey.

ENERGY UNDER THE OCEANS—EVALUATION

William Radlinski
Associate Director
U.S. Geological Survey
Washington, D. C.

The technology assessment of Outer Continental Shelf (OCS) oil and gas operations by a research team under the aegis of the Science and Public Policy Program, University of Oklahoma, is of special significance to the U.S. Geological Survey. We have the responsibility for the issuance of exploration permits and the supervision of operations authorized by leases on the OCS. And it is our job to see that this work is done in accordance with the law—safely, without damage to the environment and in keeping with optimum conservation practices.

USGS Involvement

The Survey's responsibility involves the management of more than 1,100 leases and nearly 2,000 OCS platforms in the Gulf and five in the Santa Barbara Channel. These include more than 6,200 wells and 10,000 well completions. More than 800 requests for permits to drill were processed in the past year. Platforms in the Gulf are as far as 98 miles from shore and are in water depths to 373 feet. The area of drilling and producing operations covers approximately 40,000 square miles. In the Santa Barbara Channel the platforms are about six miles from shore and are in waters up to 191 feet.

We also collect royalties from production at the rate of 16 2/3 per cent. In the fiscal year that ended in June 1973, this amounted to $360 million. Production amounted to 446 million barrels of crude oil and natural gas liquids, and 3 trillion cubic feet of marketed gas, with a total value of more than $2 billion.

Accident reduction, pollution control, and environmental protection involve a number of factors, each of which contributes to an overall strategy. These include stringent regulations insuring, but not limited to:

- **Good systems designs and construction.**
- **Redundant safety systems.**
- **Training of personnel.**
- **Accident and equipment failure reporting.**
- **Corrective action procedures.**

Currently, there are 12 OCS orders covering the Gulf of Mexico area and 10 for the Pacific Area (Santa Barbara Channel). These are the only two areas where OCS operations are now being conducted.

Other elements of our strategy are:

- **An effective inspection program.**
- **Safety motivation of operators and employees.**
- **Research and development.**
- **Third-party review of our policies and procedures.**
- **Environmental assessments.**

With these elements in mind, and with regard for problems of the future that can result from an acceleration of lease sales into new areas, deeper waters, and different environments, I comment now on the Oklahoma report.

Report Review

Overall it is very good. We welcome it and we intend to respond to each of the applicable recommendations. In fact, we already have responded to many of them as a result of implementation plans we developed in response to recommendations of three earlier reports—one by a study team from NASA, another in-house by a team of USGS systems analysts, and the third by a panel of the Marine Board of the National Academy of Engineering. A report of these plans is available from the USGS.

All four reports are compatible and many of the respective recommendations are the same. However, the Oklahoma report goes much further than any of the other three. In-depth considerations of Government management and jurisdictions are unique to the Oklahoma study, as is its plan for OCS development. The recommendations from these sections will contribute importantly to "rational OCS policy making" and to "optimal resources development," to quote objectives from the purpose of the study.

Of the 12 recommendations under "Management of Technologies," 9 are aimed directly at the Survey and 3 at industry. Of the 22 recommendations on "General Policy and Management," 10 involve the Survey. And all of the items listed under the recommendation for "Specific Technologies" directly affect the success of our lease management responsibilities.

Referring now to the category on Management of Technologies, herewith is the status, in brief, on the 9 recommendations applicable to the Survey:

Standards—Standards for the critical items of equipment are being developed under a joint American Petroleum Institute-USGS committee arrangement that involves the Offshore Operators' Committee and the Western Oil and Gas Assn. These will be submitted to the American National Standards Institute or other appropriate standards-setting organizations for review, and included in OCS Orders by reference. Quality control procedures for manufacturers are included.

Failure Reporting—As announced in our news release of June 14, 1973, we intend to establish a failure reporting and corrective action system. A "safety-alert" system for immediate reporting to all lessees of equipment malfunctions, accidents or near accidents is already in effect.

Review Technology—A Review Committee under the auspices of the Marine Board, National Academy of Engineering has already been established to serve as a third-party audit of our procedures and operations and to review state-of-the-art technologies.

Personnel Training—A joint American Petroleum Institute-USGS committee is already working at establishing curricula and training requirements for operating Personnel. We are also establishing formal training requirements for our inspectors.

Industry Cooperation—The joint American Petroleum Institute-USGS committee on training is also developing programs for safety motivation. We have already obtained a Department of Justice opinion that information exchange in the interest of safety and environmental protection is not in violation of Anti-Trust Laws.

Subsea Production Systems—The first OCS proposal for a subsea production system (i.e., more than one well) is presented in a draft Environmental Impact Statement now being aired publicly for the development of the Santa Ynez unit in the Santa Barbara Channel.

There are, of course, some conclusions and recommendations in the report with which we do not agree, and we are aware of disagreements by others, both pro and con. But this is to be expected from a 380-page report of a study as comprehensive as this one was. Disagreements are, of course, healthy, for they prompt dialogue and help bring out the facts. But in some cases, they have been presented out of context in support of an extreme position, either to discredit the entire report or as a basis for condemnation of all OCS development.

It is important to recognize the overall objective of the study—to insure that development of the OCS is optimal in a broad social sense—and to recognize that individual recommendations are made in the context of improving, not condemning, OCS development. This is the way we in the Geological Survey are viewing it, and I feel certain this was the intent of the Assessment Group.

Non-Concurrence Discussed

Our reasons for not agreeing with three of the recommendations in the Management of Technologies part of the report are as follows:

Accident Investigation—We have not established a board similar to the National Transportation Board to investigate OCS accidents. Our present practice is to have all accidents investigated by Survey personnel in accordance with fixed procedures. Major accident reports will be submitted to our Review Committee (mentioned earlier) for review. While we consider this procedure adequate for the present, we will give further consideration to the establishment of a separate board. We do intend that all reports of major accidents will be made public.

Personnel Standards—We have not yet concluded that certification of company personnel is a viable procedure for insuring performance. Our present objectives are to establish required standards for training or experience before allowing operations to proceed. Certification, *per se*, involves numerous problems of establishing certification authorities, updating, employee union regulations, and State laws. We feel that training and experience standards may serve the purpose effectively.

Government R&D—We have not established an in-house research, development, and testing program for a very practical reason—no funds. But that is not the total reason. We should have some capability for research, but we feel that the ultimate responsibility for safety and pollution prevention rests with industry. Accordingly, our approach was to establish an American Petroleum Institute-USGS R&D committee to encourage industry in this activity. A list of pertinent R&D items under investigation is being completed together with a list of those items that require new or improved development. We have informed industry that in those cases where they do not respond to R&D needs, the Government will undertake the work. But even so, public funds will need to be provided.

Concerning findings of other parts of the study—the publication of a list of "Inadequate Components," called for in the recommendation under "Specific Technologies," will be a natural result of our aforementioned failure reporting and corrective action system. Further, these results will provide information to an established research committee to identify items for research and development. The lists of components to be developed, improved, and deployed will be passed on to the R&D committee and to a Standards Committee which is currently very active. The latter committee, by the way, already has drafted detailed standards for improved downhole safety devices which are currently being reviewed. Sand probe development and standards are high on the list of priorities.

Finally, I shall comment on the "General Policy and Management" part of the report. While we agree that promotion and regulation functions should remain divided between the Bureau of Land Management (BLM) and USGS to provide a continuous checking mechanism, we do not agree that the Survey should take the lead in preparing programmatic environmental impact statements. Programmatic concerns should remain the responsibility of BLM or the Council on Environmental Quality, as is the case in the environmental assessment of the Atlantic and Gulf of Alaska OCS. We, as well as the National Oceanic and Atmospheric Administration (NOAA) and many others, provide the geologic, geophysical, seismic and other environmental data and analyses that are necessary for a full environmental impact assessment. I believe this procedure complies better with the intent, if not the organizational structure, of the study recommendations. The matter of sufficiency of data is, of course, a budget problem.

Concerning the concentration in the USGS of all management responsibilities on the OCS, we are currently working with the Office of Pipeline Safety to specify our respective roles. We met with the Occupational Safety and Health Administration along the same lines; we are developing understandings with the Environmental Protection Agency, and we do support the Federal Power Commission in providing estimates of recoverable gas reserves.

Lastly, by a recent policy decision, we now publish all new and revised OCS Orders in the *Federal Register* for public comment.

Conclusion

There have been numerous studies, reports, meetings, symposia, and legal actions concerning the development of the OCS. Several are in progress and many more will come. And this is as it should be—on the one side we have a need for the vast mineral resources that lie beneath the ocean floor, and on the other side there is a grave concern over the effects that the exploitation of these resources will have on the environment and hence our future well-being.

The significance of the offshore to our national well-being, especially in these times of critical energy shortages, is clear when one realizes that over 11 per cent of the total U.S. oil production and 13 per cent of the gas production came from the OCS in the past year; that this production in confined to a very small portion of those OCS areas which have petroleum potential; and that discovery and development will hopefully be accelerated as a result of tripling the offerings to three one-million acre lease sales per year.

The Oklahoma report has gone a long way in identifying means of improving development in this important area, and we commend both NSF-RANN and the University of Oklahoma on the study.

IMPROVED TECHNIQUES FOR GASIFYING COAL

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Our nation's capability for producing natural gas peaked in about 1965, and the chokes came off our gas wells in 1972. We now are producing gas flat out, yet supply cannot keep up with demand. In a very few years, production from deposits of high grade gas will decline. We may be able to hold our own in gas production for 20 years or so, through vigorous exploration as well as production from tighter rock formations and from smaller, more isolated deposits of gas. Early in the 21st Century, however, gas production will begin an inevitable decline.

There is time, perhaps, to do something about the problem of our declining gas supply in the 21st Century. But what about immediate economic effects? Growth in natural gas represented more than one-half of the growth in the United States fuel market between 1947 and 1972. Inability to sustain this growth in 1972 was a sudden, drastic change in the U.S. economic scene, creating problems long before the current winter's crisis.

I have a nephew in Illinois who grows corn and soybeans. Last winter he had a hard time getting propane, because grain dealers could not get natural gas and had bought up the supply of propane with which to dry grain. Many cities of the South were subject to periodic electricity blackouts. Brick kilns fired with gas were idle. This had a sharp effect on the construction industry, which was also hampered by lack of gas for new homes. Schools were cold. Withdrawal of fuel from the steel industry caused a shift to burning heavy tars in open-hearth furnaces that formerly went to the aluminum industry to serve as binder in making electrode coke. No new ammonia plants have been announced for some time. A fertilizer shortage looms. One could go on and on about the domino effects of the topping out of gas production.

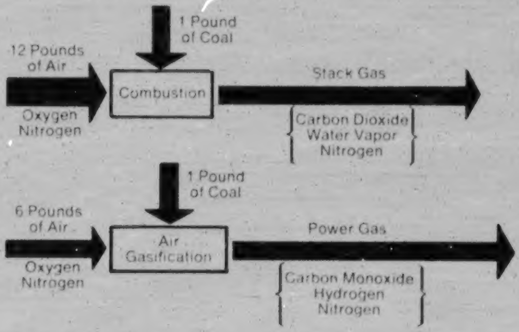
The nation urgently needs new supplies of clean fuel. Plants cannot be built quickly to convert coal to pipeline-quality gas, which must comprise essentially methane and little else. Plants cannot be built quickly to convert coal to liquid fuels. Fortunately, however, we know how to gasify coal with air, and plants could be built quickly to provide a fuel gas that could replace large amounts of natural gas which is used to generate electricity.

Gasification

What is "air gasification"? Another term for it would be "partial combustion." In Figure 1, we see that if coal is burned with about one-half of the air needed for complete combustion, the product is a lean fuel gas consisting mostly of carbon monoxide, a fuel species, and nitrogen from the air. Before about 1920, this gas was used widely by industry—even to generate electricity—and was called "power gas." The heating value of power gas, per unit volume of the gas, is about one-sixth that of natural gas. Power gas could not be exchanged for pipeline-quality gas for use in homes or small business. But it would be a good fuel for generating electricity, for industrial heat and even for drying grain.

Gas producers much like those in common use in the 19th Century could supply brick kilns and large bakeries and a wide variety of industries that now use gas. Small gas producers were not uncommon on farms in 1920, providing fuel to gas engines for stationary power. They could be used again in large numbers for many farm energy

Figure 1



needs. They could again ride piggyback on trucks and buses, as they did in many countries of Europe during World War II, to supply fuel to engines.

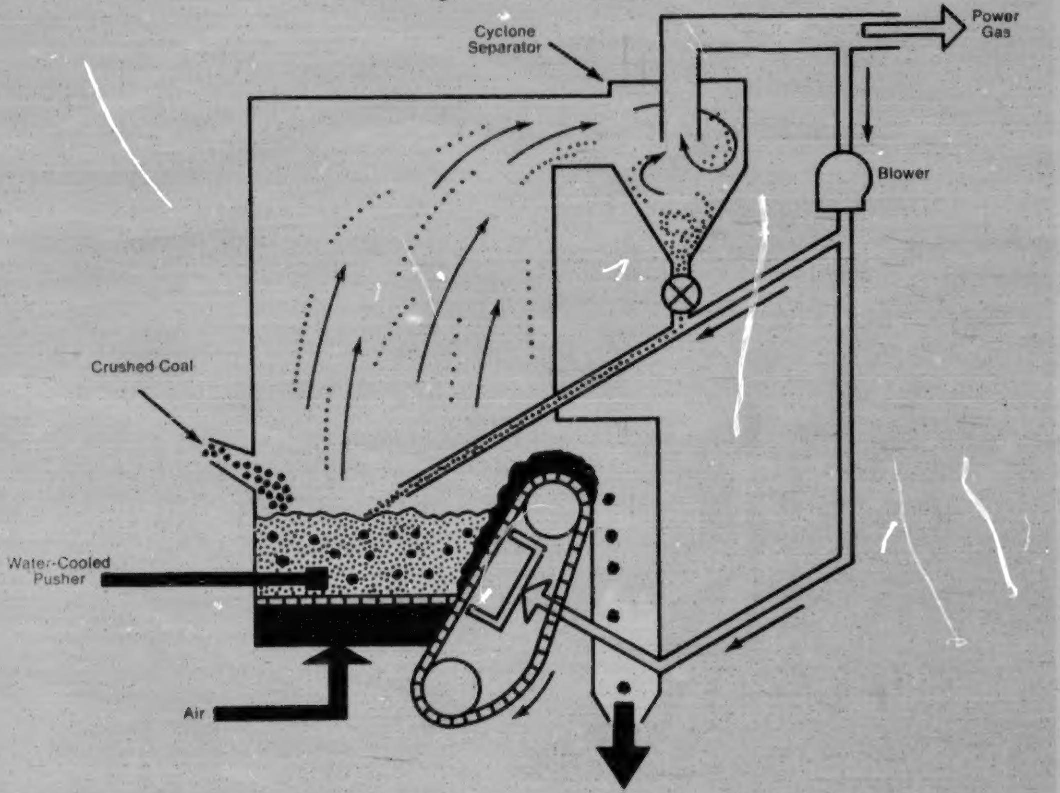
Gasifier Described

The historic producers are, however, too small for our electricity industry. Our team at The City College, under its grant from the RANN Program of the National Science Foundation, has addressed the problem of providing an air-blown gasifier having a capacity to meet our electricity industry's need.

Figure 2 is a diagram of The City College "Mark I Gasifier." It is our first result under our RANN Grant that is ready to go commercial. It is a simple revamp of the gasifier that Albert Godel and Babcock-Atlantique provide in their "Ignifluid Boiler." This marvellous French invention, which we have seen in operation and have studied intensively during the past year, is operating today in Morocco, France, Scotland, and even Korea. If these countries can gasify coal, surely we can, too! Our revamp of the Ignifluid gasifier would make gas of better quality. It is a design that uses well-proven techniques and equipment. It could be built at once with great confidence to supply gas for 30 megawatts, the scale of each of the two Ignifluid gasifiers at Casablanca, Morocco. It could be scaled up quickly to far larger size.

In Figure 2, air is introduced at high velocity through a grate into a bed of coals, setting the bed into rapid and violent motion, and creating what the chemical engineer calls a "fluidized bed." Partial combustion of the coal generates a temperature between approximately 2200° and

Figure 2—**Mark I Gasifier**



2400 Fahrenheit. As the coal is gasified, ash matter is released, and small clinkers of ash form throughout the fluidized bed. The clinkers grow in size in a regular manner. That is to say, they do not grow catastrophically to a huge clinker mass that would obstruct the flow of air upward through the fluidized bed. From time to time, a clinker comes to rest on the grate, where a pusher moves it to an escalator. The escalator carries a pad of clinker upward and out of the bed. Then it drops the pad into an ash pit for disposal. The escalating grate is cooled by a recycle stream of fuel gas.

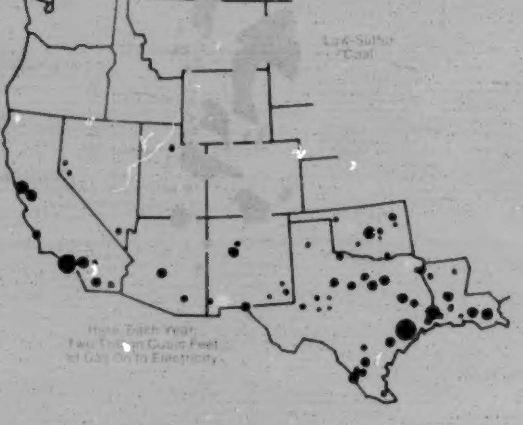
The very high air velocity of the Ignifluid boiler and the Mark I Gasifier must be emphasized. It is about 30 to 40 feet per second, more than 10 times greater than velocities used in current practice in most fluidized beds of fine particles. Accordingly, the Mark I is a device capable of achieving high capacity. A design for 300 megawatts can easily be visualized.

Albert Godel of Paris deserves great credit for his surprising discovery that ash agglomerates grow in a regular manner, non-catastrophically, in a high-velocity fluidized bed of coals undergoing gasification at a temperature beyond that at which the ash becomes sticky. At The City College, we call this the "Godel phenomenon." Godel's clinkers contain little carbon. Ash sticks to ash only, not to carbon. We expect the Mark I Gasifier to consume more than 99 per cent of its fuel.

Conversion to Power Gas

In the South and Southwest (see Figure 3), roughly between New Orleans and San Francisco, are gas-fired electricity stations using more than 2 trillion cubic feet of natural gas each year. This is roughly one-tenth of the nation's gas consumption. Perhaps another 2 trillion cubic feet go into industrial boilers. These power stations and boilers were built to fire gas only, and they could not be converted to fire coal directly. Many of them could, however, be converted to fire power gas from our Mark I Gasifier.

Figure 3



We propose that this be done as promptly as possible. Western coal is low in sulfur. Thus there will be no need to provide equipment for removing sulfur from our power gas. The fly carbon from the gasifier will be coarse by comparison with fly ash from the firing of pulverized coal, and mechanical dust separators will be adequate.

Coal now is being shipped from Wyoming and Montana to Illinois. There are plans for shipping it to Michigan, Texas, Louisiana and even Florida, a continent away. Railroads should be able to provide rolling stock and engines to haul the coal—about 100 million tons per year to replace 2 trillion cubic feet of gas. Expansion of our Western operations for excavating coal may be the most difficult part of our proposal. This must be improved as regards "reconstruction" of the land surface as well as regards simple good manners toward a surface mine's immediate neighbors. "Restoration" is out of the question.

The following is a program to obtain several trillion cubic feet of "new" gas for American homes and businesses in four to five years:

Winter of 1974-75
Several tests at about 30 megawatts.

Winter of 1975-76
About 20 units at 100-200 megawatts.

Winter of 1976-77
About 1 trillion cubic feet of "new" gas.

I see no other way to accomplish this result so quickly. Implementation of this program can ease the demand for propane and help my nephew supply the nation with corn and soybeans. The program can release gas for new home construction and business expansion.

This, of course, is not just a program for the electricity industry or for the gas industry. Our energy supplies are highly interrelated, and relief at one point will provide relief all down the line.

I would add that we must back out oil from electricity generation, too, but this will take longer. Much oil-fired capacity is on the East Coast, where we will no doubt shortly see deliveries of low-sulfur Western coal. Massachusetts is already receiving low-sulfur coal from Poland. Most of the oil, however, must be displaced by high-sulfur Eastern coal, and a step must be added to remove sulfur from the Mark I power gas.

The program I have now described, built around the Mark I Gasifier, is vital for the immediate future. But it is not good enough for the long run.

We need to make pipeline-quality gas from coal, as well as power gas.

We need to make liquid fuels.

We need to make clean sulfur-free power gas at elevated pressure for firing gas turbines. We cannot do this in our "primitive" Mark I Gasifier.

Coal is a complex material from the chemical viewpoint. Part of it can be removed as a fuel vapor simply by applying heat, and we should be able to "skim some cream" by converting this "easy" part of coal into pipeline-quality gas and valuable liquids.

Coalplex Described

The team at The City College began its work under a RANN Grant in June 1972, with a research plan aimed at the 5-to-10-year time frame. Our Mark I Gasifier was an unexpected result, inspired by recent events in the Middle East. The City College Coalplex (Figure 4) would convert coal into three products: substitute pipeline gas, benzene suitable for blending into high-octane gasoline and also valuable to the chemical industry, and clean electricity.

In the Coalplex, flash treatment of coal with hydrogen would convert the "easy" part of coal into methane and benzene. A coke residue would be gasified with high-pressure air to supply gas at high pressure for firing gas turbines. These would work together with steam turbines to generate electricity. The power gas would, of course, be cleaned to get rid of dust and sulfur.

We are obtaining exciting results from our panel bed filter. It seems to be capable of removing fine dust, of a size comparable to power-station fly ash, from hot gas at efficiencies beyond 99.9 per cent. We believe that removal of particulates smaller than 1 micron will be beyond 99 per cent. It is a granular-bed filter, and the granules that make up the bed might be a solid reagent, such as iron oxide or dolomite, capable of absorbing sulfur species present in the power gas.

Mark II Gasifier

Our Mark II Gasifier (Figure 5) uses a "fast fluidized bed," an exciting new technology for bringing finely crushed coal into contact with air. The Mark II also uses the Godel technique

Figure 4 – **CCNY COALPLEX**
A Near Term Development

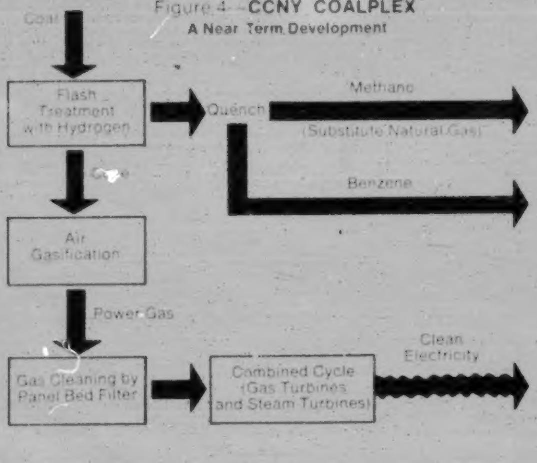
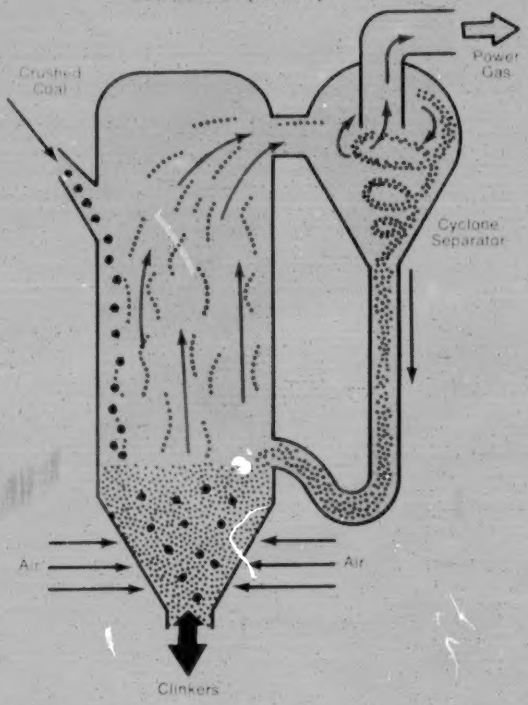

Coal
Flash Treatment with Hydrogen
Quench
Methane
(Substitute Natural Gas)
Benzene
Coke
Air Gasification
Power Gas
Gas Cleaning by Panel Bed Filter
Combined Cycle (Gas Turbines and Steam Turbines)
Clean Electricity

Figure 5 – **City College Fast Fluidizer Bed Gasifier (Mark II)**


Crushed Coal
Power Gas
Cyclone Separator
Air
Air
Clinkers

for removing ash matter in form of clinkers. It houses the fluidized bed in a circular vessel capable of operating at high pressure.

Air blows upward through a cylindrical vessel at high pressure and at high velocity, between about 10 and 20 feet per second. Crushed coal is added, and its reaction with air brings the temperature to about 2200° Fahrenheit. The air sets the coal into violent motion. As the coal is gasified, clinkers form and drop to the bottom and are removed. The rising gases carry fine particles from the top of the cylindrical vessel and into a "cyclone," where the gas whirls and whips the particles toward a cylindrical wall. The solids fall downward along this wall, and a pipe carries the solids back to the bottom of the first vessel. Power gas leaves the cyclone at high pressure, relatively free of solids. But of course it must be cleaned further to remove sulfur species and last traces of dust.

A major advantage of the Mark II is its high capacity. We calculate that a vessel with an inside diameter of 11 feet and a height of 50 feet will handle 3,000 tons of coal a day and will provide power gas sufficient for 300 megawatts. This is a good match for combined-cycle equipment that the electricity industry is now building at about 20 locations.

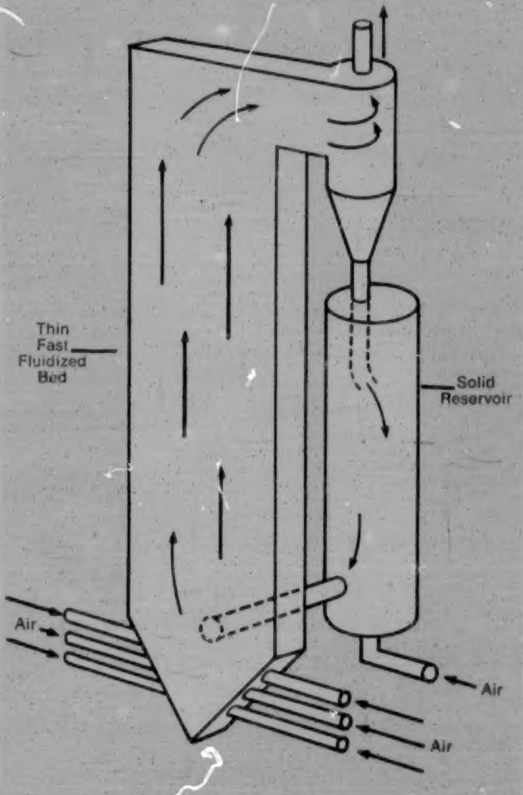
The class of gas turbine expected by about 1978 will permit a combined cycle employing the Mark II Gasifier followed by a panel bed filter to operate at efficiencies beyond 45 percent for conversion of thermal energy in coal to electricity. This will represent fuel savings of 15 to 20 per cent by comparison with present practice, and of course there will be no harmful emissions of dust and sulfur dioxide. Elemental sulfur will be a by-product of the system. With a concentrated effort, this system might be ready in 1979.

Model of Fast Bed

To study the motion of fine coal particles in our fast fluidized bed gasifier, we have built a model made of plexiglas for visual study (Figure 6).

In all chemical engineering, the subject we know least about is that of bringing fine particles into intimate contact with gases—especially at the high velocities we have selected for our fast bed gasifier. We have much to learn from scientific study of the turbulent mixing of solids and gas in our model. But, in the meantime, this is a subject for which the eyeball is a great teacher. Anyone would be foolish to build a novel gasifier without first building a transparent model simply to take a look at what is going on.

Figure 6—**Gasifier Model for Visual Study Using White Solid**



The model is thin in one direction, for better viewing. We use white particles in the model so that we can see better what is happening. When the model is lit from behind, the white particles appear black.

Figure 7 shows the V-shaped bottom of our "thin" model, simulating the conical bottom of a cylindrical vessel. Air is introduced via horizontal pipes that penetrate the two sides of the V, and also from inlets partway up one side of the thin model. The vigorous activity of the fluidized solids is apparent.

The cyclonic action whips particles toward the cyclone's cylindrical wall. From there, the solid flows through tubes into a round reservoir that serves to return the flow of solid into the bottom of the thin fast fluidized bed.

Figure 7

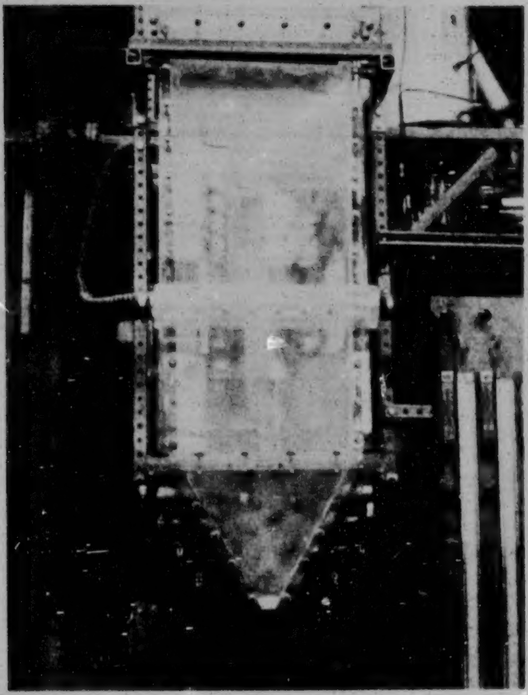


Figure 8

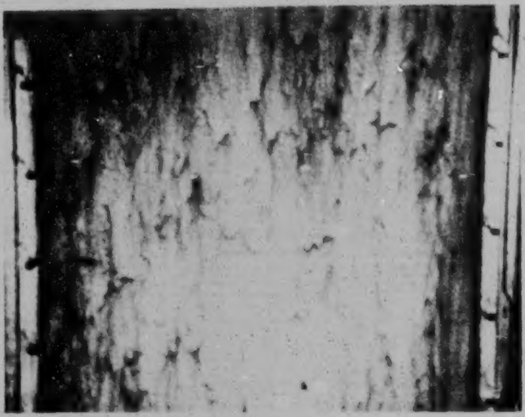


Figure 8 is a close-up, taken from a frame of motion picture film, of the fast fluidized bed near the middle of the thin model. The solid falls in sheets that look much like sheets of water in a lively fountain. This phenomenon truly should be termed "fluidization."

In addition to the thin model, there will be three fast-bed models that are round: a first bed 3 inches in diameter, a second at 6 inches and a third at 12 inches. The first two are already up. Our plan is to obtain data in the thin model and in the three round sizes. From all of this data, we plan to determine the engineering problems associated with building a model at a diameter of 11 feet. This is the size needed to provide power gas for 300 megawatts.

Three points deserve emphasis.

The mixing in the fast bed is far more vigorous than one sees in conventional "slow" fluidized beds that have been commonly used in the past.

Secondly, our fast bed will operate at a throughput of material roughly ten times greater than slow beds can afford.

Finally, we are confident that our fast fluidized bed will give superior performance at the same time that it gives far higher capacity for gasifying coal.

ENERGY CONVERSION AND STORAGE TECHNOLOGY— THE SODIUM-SULFUR BATTERY

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Vice President, Scientific Research
Ford Motor Company
Dearborn, Michigan

The energy crisis is probably the most discussed topic in the news these days—and for good reason. It touches everyone. We have been told that the United States should expect severe heating oil shortages this winter and gasoline shortages appear likely this winter and certain by next summer. With every new day, consumer coupon rationing of gasoline and heating oil is being discussed more actively.

Even as recently as a year ago, most of us would not have predicted that we might be forced to accommodate before the end of 1974 to the unpleasant task of readjusting our way of life to this drastic change in energy availability.

And not only will personal comfort be affected in the years ahead, but also our manufacturing productivity will be hit hard. With world energy consumption expected to double by the 1980's, we must look at every alternative for expanding our energy resources.

We in the automobile business often are asked why we have not built electrically powered vehicles to alleviate the problem of exhaust emissions and now to combat the shortage of gasoline. First, and as we will discuss further in a moment, the performance of presently feasible electric vehicles just does not measure up to the performance of vehicles powered by internal combustion engines. They simply cannot perform on the highway in a fashion that is typical of the standard gasoline-powered vehicle.

As for emissions, the traditional answer is that electric vehicles would merely transfer the pollution problem from the vehicle to the electrical generating plant. Therefore, converting to electric vehicles would result in no net benefit. This answer is really a bit too simple. Whether it is cheaper and easier to reduce pollutants at a central power generating station or in the exhaust of each vehicle is a complex problem for which there is probably no single best answer.

Such factors as the nature and extent of the fuel supplies, the type and concentration of the pollutants that can be tolerated, the location at which the pollutants are emitted, the local meteorological conditions and the status of the various control technologies must be considered.

Within the present technology of electric and internal-combustion powered vehicles, the overall system efficiency, as measured by the fraction of the energy in the primary fuel that is converted to useful torque at the wheels of a vehicle, is essentially the same.

Clearly, if significant improvements are made in the efficiencies of any of the sub-elements—either in generation, transmission or utilization of electricity—this could affect the attractiveness of electric vehicles. Thus, we must continue to examine the various alternatives for energy production and utilization and the trade-offs that are possible within this complex problem.

Can Electricity Compete?

For a number of years, Ford scientists and engineers have studied the aspect of this problem that deals with the conversion and storage of electrical energy and the extent to which electricity can compete favorably with liquid fuel for powering vehicles.

In this presentation, I would like to discuss the development of a new storage system and the possible advantages that it can offer over the standard lead-acid battery system both in the storage of extra electrical energy and in providing energy for mobile vehicle propulsion. At first, let us concentrate on the development of a new battery technology.

As a basis for orientation, we will compare the performance of a 3,200-pound vehicle when propelled by either an internal-combustion engine or a direct-current electric motor. This weight class is chosen arbitrarily, but it is reasonably representative of the compact class vehicle. The projected operating characteristics are shown in the two columns on the left of Figure 1 for an electric vehicle with lead-acid batteries and on the right for a standard 2.3-liter internal-combustion engine with automatic transmission.

Figure 1—**City Vehicle-Performance (3200 Lb. Gross Wgt.)**

	Electric Drive (Lead-Acid Battery)		Internal Combustion Engine
Payload (Lbs.)	300		800
Motor	30 hp.	17 hp.	2.3L*
Range Per Charge (Miles)			
—20 mph	48	58	273
—City Driving	28	34	233
Acceleration Distance in 10 Sec. (Ft.)	365	230	373

* With automatic transmission.

An electric vehicle with the characteristics described in the far left column has reasonably high performance, as measured by the maximum distance traveled in ten seconds, starting from rest. As this suggests, it is technically possible to build an electric vehicle that is essentially equivalent to the internal combustion vehicle by this single criterion, but the range and payload of the electric vehicle are very limited. The middle column indicates the limited trade-offs that can be effected between performance and range for the same vehicle—still powered with lead-acid batteries. Not only are the range and payload of this vehicle limited, but it would have unacceptable performance. The column on the right gives the data for this vehicle weight when powered by an internal combustion engine. Obviously, neither of the electric vehicles has the desirable operating characteristics of the internal combustion engine.

Figure 2 presents the projected operating costs for these same vehicles. For purposes of this comparison, the gasoline tax has been removed from the figures on the right. The limitation in the performance of the electric vehicle, although somewhat affected by motor design and controller design, is determined almost entirely by the battery system. This poor performance can be traced directly to the problem of how much battery weight can be accommodated in the electric vehicle. Thus, it relates directly to the low energy density of the lead-acid battery. The total operating cost of the system also is affected strongly by the relatively limited number of charges and discharges that the lead-acid batteries can sustain, for this determines the battery lifetime. This leads us to believe that only through the development of battery systems superior to those of lead-acid can a major adjustment in electric propulsion be achieved.

Figure 2—**City Vehicle-Operating Costs (3200 Lb. Gross Wgt.)**

	Electric Drive (Lead-Acid Battery)		Internal Combustion Engine
Motor	30 hp.	17 hp.	2.3L**
Fuel Cost (c/Mi.)	1.1*	0.9*	1.4*
Operating Cost (c/Mi.)	4.2	3.8	2.1
Total Vehicle Cost (c/mi.)	8.3	7.8	5.6

* Taxes not included.
** With automatic transmission.

What are the potentials in terms of a chemical storage system?

Figure 3 depicts the energy densities of same common systems in units of watt-hours per pound. The higher the energy density, the less battery weight that one needs for a given performance.

Figure 3—**Energy Densities of Some Common Systems (Watt-Hrs./Pound)**

	Theoretical	Actual
Lead-Acid	49	10
Silver-Zinc	230	50
Sodium-Sulfur	350	100*
Zinc-Oxygen	495	60*
Lithium-Sulfur	660	100*
Lithium-Copper Flouride	646	100
Lithium-Chlorine	990	250
Gasoline	6000	1200

* Projected

Starting with lead-acid, we find the energy density in watts per pound increasing as we progress from the lead-acid system to the sodium sulfur system and finally to the lithium-chlorine system. For purposes of comparison, the energy density for gasoline, which is substantially greater than that of the battery systems, also is given. Even though the energy density of gasoline cannot be achieved by the chemical storage systems described above, a factor of ten improvement in range would make the electric vehicle much more attractive. An improvement in energy density of the battery system by this factor over lead-acid would enhance materially the attractiveness of the electric vehicle. This, in fact, seems possible. There are other considerations, however.

In addition to the energy density, the battery system must have a high power density, a long life (which means many charges and discharges) and low cost.

Let me now mention very briefly the role that energy storage devices can play in improving the efficiency of electrical generating and transmission systems. Improved efficiency for the electrical generating system can be achieved by operating it near peak power at all times with a capability for storing any electrical energy that is not needed immediately. Thus, the overall efficiency for power generation is improved if energy can be generated, say at night, for use during the peak demand periods that occur during the day. Improvements in energy and power density and lifetime of batteries over that available from lead-acid batteries are also needed for power system applications. Thus the criteria for the batteries are very similar.

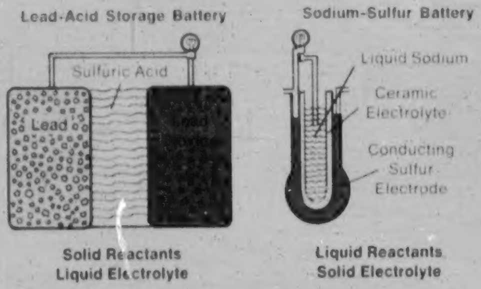
Sodium-Sulfur Best Chance

After a thorough study of the various possible battery systems, we concluded that the sodium-sulfur system offers the best chance of achieving all of the objectives we seek and thus of providing improved capability for both electric propulsion and power system peak load leveling.

The development of the sodium-sulfur battery began at Ford Motor Company a decade ago—in 1963. During this ten-year span, we have been concerned with the development of engineering prototypes, as well as with understanding the fundamental mechanisms that take place in this system.

Figure 4 illustrates the nature of the sodium-sulfur battery and shows how it differs from the lead-acid battery. On the left is a diagram of the standard lead-acid battery with solid electrodes of lead and lead dioxide, separated by sulfuric acid, the liquid electrolyte. On discharge, the energy is extracted by the external circuit and both the electrodes undergo chemical change. The number of charges and discharges are limited, at least in part, by irreversible changes that take place in the electrodes.

Figure 4—**Lead-Acid vs. Sodium-Sulfur Battery**



By contrast, the sodium-sulfur battery has liquid electrodes, sodium and sulfur, which are separated by a solid electrolyte—a form of ceramic known as beta-alumina. During discharge, a sodium atom gives up an electron to the external circuit, migrates through the solid electrolyte and reacts with the sulfur on the other side to form a compound of sodium and sulfur. Ideally, there is no chemical or physical change that takes place in the ceramic electrolyte during the charge or discharge, and the chemical changes of the electrodes are completely reversible. The characteristics of the inert electrolyte make possible important trade-offs between the energy and power. In the sodium-sulfur battery, the total stored energy depends only upon the total weight of the sodium and sulfur, whereas the power density is related directly to the total surface area of the ceramic electrolyte.

For a vehicle, the stored energy is related directly to the achievable range; whereas, the power density is related to the achievable acceleration of the vehicle. Since one of the most costly components of the battery is the ceramic electrolyte, it will be advantageous economically to tailor this battery to the amount of ceramic that is used. Where weight is critical, as in the vehicle, a high energy and power density is required.

The objectives of the development of the sodium sulfur battery are shown in Figure 5. For electric propulsion, we believe we need:

- **An energy density of 100 watt-hours per pound.**
- **A power density of 100 watts per pound.**
- **A durability of five years (which can be expressed in terms of a desired charge and discharge of about one thousand cycles).**
- **A cost of approximately two to three dollars per pound.**

When used for load leveling in a generating and transmission system, we believe the energy density and power density can be somewhat lower, since weight is not such a problem. However, the durability should be about 25 years. We project the desired cost for this application to be between $5 and $15 per kilowatt-hour of stored energy—somewhat lower than the projected cost of batteries that are to be used for automotive propulsion.

Figure 5—**Sodium-Sulfur Battery Development Objectives**

	Electric Vehicles	Load Leveling
Energy Density (Watt Hrs./Lb.)	100	25
Power Density (Watts/Lb.)	100	25
Durability (Yrs.)	5 (1000-Cycles)	25
Cost ($/Kwhr.)	20	5-15

As with any new application, several problems must be solved before this system can become operational. The sodium polysulfide melt that results from the chemical reaction of sulfur and sodium is corrosive and proper materials must be developed for its containment at the temperature of 575° Fahrenheit that is needed to maintain the electrodes in a liquid form. Thermal insulation and careful control of the temperature must be provided. Inexpensive processing methods for the manufacture of the ceramic need to be developed. Although the initial work indicates that none of these problems are insurmountable, we have a long way to go to make this a commercial system.

Figure 6 compares the performance of an internal combustion engine with an electric vehicle equipped with the type of sodium-sulfur battery that will meet our objectives. You will notice that for a comparable performance, as determined by the acceleration, a range can be achieved that is at least as large as that of an internal combustion engine with a normal-sized tank of gasoline.

Figure 6—**City Vehicle-Performance (3200 Lb. Gross Wgt.)**

	Electric Drive (Sodium-Sulfur Battery)	Internal Combustion Engine
Payload (Lbs.)	300	800
Motor	30 hp.	2.3L*
Range per Charge (Miles)		
—20 mph	483	273
—City Driving	280	233
Acceleration Distance in 10 Sec. (Ft.)	365	373

* With automatic transmission.

An estimate of the operating cost of this vehicle is given in Figure 7.

Figure 7—**City Vehicle-Operating Costs (3200 Lb. Gross Wgt.)**

	Electric Drive (Sodium-Sulfur Battery)	Internal Combustion Engine
Motor	30 hp.	2.3L**
Fuel Cost (c/Mi.)	1.0*	1.4*
Operating Cost (c/Mi.)	1.7	2.1
Total Vehicle Cost (c/Mi.)	8.2	5.6

* Taxes not included.
** With automatic transmission.

Although the operating cost per mile seems to compare favorably with that of the internal combustion engine, the total vehicle operating cost per mile in city driving will be higher because we expect the cost of the electric motor controller and the sodium-sulfur battery system to continue to be higher than the cost of an internal combustion engine.

Since the cost figures of operating an internal combustion engine are taken from Department of Transportation data showing averages for the past 10 years, they do not reflect recent increases in the cost of gasoline and, therefore, must be considered low. Similarly, the cost of electricity is only an average. Again, to aid in comparison, taxes are removed from both the cost of gasoline and electricity.

A Potential Competitor

We are optimistic about the potential of the sodium-sulfur battery. Its successful application to an electric vehicle would provide performance in terms of range, durability and operating costs that would compete favorably with the present-day internal-combustion system. But the electric vehicle still will have many deficiencies.

First, the payload would be less than that of the gasoline-powered vehicle simply because we see no way for the energy density of the battery to be brought up to that of gasoline. This would mean that electric cars could accommodate fewer passengers than would be the case for the same gross-weight vehicle powered by an internal combustion engine. Providing auxiliary functions, such as heating and air conditioning, will degrade the overall performance of the electric vehicle more than the internal combustion engine vehicle.

The National Science Foundation, through its program of Research as Applied to National Needs, recognized that the battery is a vital subelement in a transportation system involving electrical propulsion and in electric peak power storage.

In an effort to expand the research in this critical area, it awarded a contract to Ford Motor Company in June of 1973 to pursue the application of the sodium-sulfur battery, as one means of attacking the energy crisis.

Objectives of the research project are to:

- **Develop a better understanding of the interaction of sulfur and sodium at the surface of the ceramic.**
- **Determine the optimal properties for the conductive ceramic.**
- **Develop low-cost techniques for mass production of that ceramic.**

This basic understanding is to be translated into prototype cells that will be tested under realistic conditions. The contract was undertaken as a joint project between Ford Motor Company in Dearborn, Mich., and two major universities—the University of Utah in Salt Lake City and Rensselaer Polytechnic Institute in Troy, N. Y. Work on the project is under way in laboratories at all three locations. Close coordination is maintained through frequent meetings, and a senior member of the Ford group is spending 1974 at the University of Utah working with researchers there. Members of the Rensselaer Polytechnic Institute group are expected to spend the summer months at the Ford laboratory. Every effort is being made to assure close interaction between the various activities. We feel that students and faculty are a vital part of this research effort.

Cooperation Essential

We believe this interaction between a major government agency, the academic community and an industrial laboratory offers great promise of developing a new technology that will benefit a number of problem areas for a wide range of energy users. I would like to close by spending just a moment on this point. We are appalled at the recent popular and technical press articles which suggested that government and industry and universities cannot work together successfully for the common good without being improperly influenced or biased by each other. This suggestion is contrary to the long tradition of objective scientific research and in view of today's critical energy problems, should not even be entertained.

It is imperative that all scholars and technicians who can contribute to solving the crisis confronting us employ their talents and resources to attack the problem effectively. I am convinced that the most efficient way to accomplish this is through joint programs in which each participant presents his analysis of the problem to his fellow participant and thereby shares the responsibility for finding the solution to the tough problems we face. Time is too short and the problems are too severe to quibble about the possibility of one scientist being improperly influenced by another's thinking. No one group has all the talent or the complete range of experience to produce the results so urgently needed. When the divergent views of how to solve critical applied problems are expressed in the research and early development phases, significant results can be achieved. Cooperative research—in which the best minds of our universities and industry are brought together with government agencies to work on common problems—is not only a viable but an essential part of solving our energy problems.

It is our fervent hope that political considerations will not preclude the development of fruitful interactions among industry, university and government, for we believe this is a highly productive force that can make a concerted attack on the major applied problems that are critical to our nation's future well-being.

ENERGY TRANSMISSION SYSTEMS

John Peschon
Vice President, Systems Control, Inc.
Palo Alto, California

For many years the electric utility industry has been coping with the problem of demand growth. Thus far it has been largely successful in providing the greatly expanded generating, transmission and distribution facilities required to supply inexpensive and reliable power.

The isolated "brown-outs" and "black-outs" that have occurred highlight the great difficulties in meeting the ever-increasing demand. Consumption of electrical energy in the United States is growing at a rate approximately double that of all other forms of energy.

This growth will amount to 9 per cent in 1973. Capital investment required to provide the needed facilities amounts to $20 billion per year. The electric power industry is the nation's most capital-intensive industry.

There is clearly a need to establish priorities for future program development to form a technological base on which the successful supply of electric energy increasingly depends.

Study of Systems Analysis Needs

A proposed set of priorities has been recommended by Systems Control, Inc. to the National Science Foundation. A survey was made of the present status and the research needs in systems analysis and control of large interconnected power networks. This study considers work in the United States and abroad.

Study Objectives

Emphasis was placed on identifying the important research projects that could contribute to meeting the national needs for an ever-increasing supply of electric power.

In the survey, power systems planning and operation were considered from the following standpoints:

- **Optimum use of energy sources.**
- **Impact of environmental constraints.**
- **Reliability of power supply.**
- **Control of power system transients.**
- **Local versus large centralized power-generation systems.**
- **Planning for expansion of transmission networks.**
- **Potential impact of new technologies.**

The study established guidelines for RANN and the research community to use in identifying important areas for development to meet the needs of the electric utility industry. In addition, it provided guidance for the development of closer cooperation between the utility industry and the research community, which could result in additional applications of research results to real power systems.

High Priority Areas

The result was a list of the highest priority research and development objectives facing the utility industry. They are:

- **Long distance networks interconnections.**
- **Distributed electrical generation systems.**
- **Load management.**
- **Environmental impact.**
- **Long-term system load forecasting.**
- **Methods of cost-sharing facilities.**

Long Distance Interconnections—The present trend is toward increasingly complex interconnections possibly leading toward a total national grid. A national electrical grid would link existing regional areas into a network that could serve not only the United States but also Canada and Mexico.

Distributed Generation Systems—Running contrary to the long-distance interconnecting concept is that of the distributed generation system, which conceivably could utilize solid wastes and even some liquid wastes as a power source to supplement scarce fossil fuels.

Load Management—The objective of load management is to reduce total energy consumption and peak load requirements through automatic central control. Central control would shave peak loads by using selective load interruption techniques to manage power from a central point, such as a distribution substation.

Environmental Impact—Utility systems must meet present and future electrical demand within environmental, economic and reliability constraints. Environmental dispatch requires that there must be sufficient capacity in the network to select, under changing environmental conditions, the necessary mix of power plants to meet the region's power demands.

Long-Term System Load Forecasting—Long-term system load forecasting includes both total annual energy forecasts for up to 20 years and peak demand forecasts. Although simple extrapolations are often used today, more advanced system analysis techniques are needed. These would employ probabilistic methods, consider various energy utilization categories separately, and employ land-use and population data that is becoming available on a national scale.

Cost Sharing of Facilities—The trend toward larger generating units has created a situation under which two or more utilities share the cost of large facilities, both generation and transmission. A system analysis procedure is needed for estimating the benefits to each partner and a way of relating these benefits to the participation in costs. This is difficult and important particularly for transmission equipment that is shared.

Other Developments

Independent of the RANN program, additional work is already under way to make substantial contributions to the utility industry in its effort to supply adequate electric power for the country's needs.

Many new and important hardware devices already have been developed to meet increased needs for electrical power. Examples are very large 6,000 to 10,000 megawatt generating facilities (power parks), extremely high voltage alternating current transmission lines, high voltage direct current systems, the formation of reserve "power pools," and the design and operation of large interconnected power networks that are beginning to use AC-DC-AC coupling techniques.

The formation of pools and the development and operation of interconnected power networks (a national grid has been proposed) have introduced new dimensions of complexity to the systems analysis needs in electric power systems.

This depicts the complexity of modern power transmission systems in the United States that could benefit from the interconnection concept.

Conclusion

Our study has identified those problems facing the utility industry—problems that stand to benefit from intensive research and a redefinition of priorities.

Moreover, in view of the critical energy needs of the country, such redirected programs will enable the Federal government and the private sector to move quickly into programs that appear to have the best likelihood of high payoff.

THE CHALLENGE OF GEOTHERMAL ENERGY

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Rogers Engineering Company
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and

Henry Ramey, Jr.
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Geothermal energy consists of heat in rock and earth fluids at temperatures above those set by the particular process application. Probably one of the oldest uses of geothermal energy was space heating, and this use undoubtedly predates recorded history. See numerous references to hot earth "juices."[1] Today, several other current and potentially important uses for geothermal fluids exist. They include generation of electrical power, chemical process steam, process heat for water desalination and chemical content recovery. In the main, however, this paper will consider electrical power uses.

The potential and in some cases immediate commercial significance of geothermal energy is in several forms:

- **Hydrothermal reservoirs containing steam or hot waters ranging from fresh water to concentrated brines.**
- **Deep high-pressure or geopressured aquifers.**
- **Near surface intrusions of rock, for example, magma or lava.**
- **Impermeable hot, dry rock.**

Because the average increase in earth temperature below the surface is roughly known, and the heat capacity of rocks is also known, it is not difficult to compute the resource base of geothermal energy that is theoretically available. It is extremely large, and of national importance.[2]

But estimates of the fraction of the resource base that may be converted to electrical energy vary widely. Current estimates for the United States range from 600[3] to more than 400,000[4] megawatt centuries. Estimates differ because of varying assumptions regarding geologic conditions, the state-of-the-art in finding and drilling geothermal wells, economics, solution of institutional and environmental problems, and, perhaps most important, the impact of research and development on finding geothermal resources and on extending our abilities to use what is found.

At first glance the difficulty of finding geothermal resources may not be obvious. Earth heat exists everywhere. The problem is two-fold: low heat concentration and the primitive state of the technology. The average heat flux to the surface of the earth is not high enough to support electrical power generation. Thus locally high heat flux, or high concentrations of heat near the surface of the earth are needed to obtain geothermal energy in sufficient concentration for practical use. The explanation for the primitive state of geothermal technology is simply that there has been little incentive to develop geothermal energy until recently.

Using current technologies, it is economically feasible to convert geothermal energy to electricity when magma intrudes close to the surface of the earth and transfers its heat to a convecting hydrothermal reservoir containing reasonably clean fluid. The reservoir may then be produced by wells drilled to deliver the hot fluid to the surface. Steam may be produced or flashed from sufficiently hot liquid (preferably above 200° centigrade) for use in low pressure steam turbine generators,[5] but the produced fluid must be reasonably clean for the current state-of-the-art.

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[1] Hoover, H. and Hoover, L. H.: Translation from the Latin of *De Re Metallica* by G. Agricola, (1546), Dover Press, 1950.

[2] Rex, R. W., and Howell, D. J.: "Assessment of Geothermal Resources," p. 63, in Kruger, P., and Otte, C., eds.: *Geothermal Energy*, Stanford University Press, 1973.

[3] White, D. E.: "Characteristics of Geothermal Resources," *Ibid.*, p. 91.

[4] Rex, *op. cit.*

Hydrothermal Systems

There are two basic kinds of hydrothermal systems. One is the vapor-dominated reservoir from which dry steam may be produced. Examples include the steam fields at Larderello, Italy, and The Geysers, California.[6] Another important hydrothermal system contains hot water. The liquid reservoirs will provide both steam and water when well-head pressures are reduced and a portion of the water is permitted to flash to steam. If vaporization is accomplished in surface equipment, all of the heat must be supplied by the water and the fraction that will vaporize depends on water temperature and well-head pressure. A much higher fraction can be vaporized within rock pores because the rock can supply large amounts of heat on cooling. Examples of hot-water systems include Wairakei, New Zealand and Otake, Japan.[7]

Hydrothermal reservoirs can be of practically any type or age of rock, providing the rock is porous and permeable. There must be a sealing layer or cap rock of low permeability and low thermal conductivity to prevent loss of fluid and heat.

A special hydrothermal system is the geopressured system. As the name suggests, geopressured systems are pressurized in excess of static hydraulic head pressures because of the weight of the overburden exerted on the reservoir. Well-head pressures may exceed 5,000 pounds per square inch. These reservoirs contain brines often at temperatures in excess of 180° Centigrade. Also the brines are often saturated with natural gas and may contain as much as 20 cubic feet of natural gas per barrel of hot water produced. One of the larger known geopressured areas lies in a belt about 35 to 75 miles wide and extending from the Rio Grande to the Mississippi Delta.

Near-surface intrusions of volcanic molten rock or solidified hot dry rock provide another large geothermal resource. It has been estimated that a cubic mile of hot dry rock at 340° Centigrade could release the heat equivalent of 300 million barrels of crude oil on cooling to 150°. But the task remains to find methods for extracting and delivering this heat to the surface of the earth in usable form.

Electric Power Generation

For large-scale electric power generation, the state of current geothermal technology limits utilization to clean fluids. Approximately the following reservoir characteristics are necessary for steam and hot-water or brine systems:

—Depths must be economically drillable. Geothermal reservoirs in production today have not required drilling to depths greater than 10,000 feet.

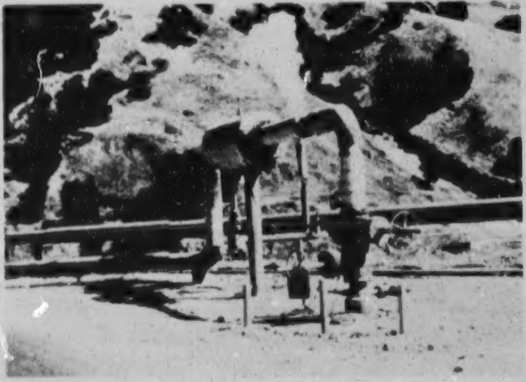
—Reservoir base temperature must be in excess of 180° Centigrade.

—Reservoir volume and rock permeability must be sufficient to sustain a high rate of steam or hot water flow. Many commercial wells today produce the equivalent of 5 megawatts per well. In Italy one currently produces the entire steam for a 15-megawatt power plant, and is reported capable of producing at twice that rate.[8]

—There must be sufficient hot fluid and a heat source adequate to sustain production over a 30-year amortized life of the power plant.

—Finally, reservoir fluids should not contain economically unmanageable quantities of dissolved salts that would cause erosion and corrosion, and environmentally harmful concentrations of chemicals such as arsenic, fluorides, mercury, and other toxic materials.

Figure 1



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[5] White, D. E., *op. cit.*

[6] Koenig, J. B.: "Worldwide Status of Geothermal Resources Development," *Geothermal Energy*, Kruger and Otte, p. 15.

[7] *Ibid.*

[8] Personal observation, H. J. R., USA-Italy Geothermal Symposium, Pisa, November 1973.

Resource Utilization

Although the geothermal resource base is vast, current technology requires the use of clean hydrothermal fluids. About a half-dozen countries utilize geothermal fluids for electric power production today. The capacity of all of these plants totals about 1,150 megawatts.

If clean steam or hot-water systems are available, the generation of power is relatively straightforward. The dry steam field at The Geysers, California, presents such an example. The steam is separated from entrained solids, and the steam is then delivered to a steam power plant turbine. Figure 1 shows a steam well-head centrifugal particle separator at The Geysers Field. The Geysers turbines are low pressured turbines operated at about 7.5 atm, slightly superheated steam about 180° Centigrade, which is condensed with direct contact condensers.

Figure 2 shows the first power plant installed at The Geysers (Units 1 and 2) in 1960 and 1961. One of the great needs of most thermal electric power plants is cooling water. Thus, one of the great attractions of the geothermal power plant is the fact that since it doesn't have a boiler, there is no need to return the condensate to the boiler. Therefore, less costly direct-contact condensers may be used and the condensate may be used as make-up water for the cooling tower; thereby eliminating the need for additional make-up water.

The thermal balance on a power plant like those in Figure 2 is such that about 80 per cent of the steam condensate is evaporated in the cooling tower, and about 20 per cent remains for disposal. Since the condensate can contain some boron compounds and ammonia, it may require discharge to other than surface drains. Disposal is effected at The Geysers by injection of the waste waters back into the steam reservoir.[9]

Figure 2

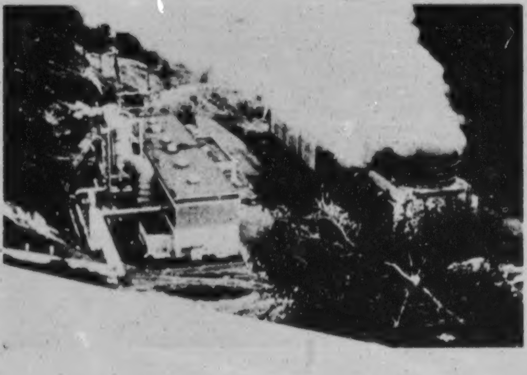

Figure 3 shows a steam separator at the Cerro Prieto plant in Mexico.[10] This is a hot water system in which the steam water mixture is brought to the surface and separated. The steam is then delivered to the power plant. The waste waters are taken to an exhaust vent silencer and flashed to atmospheric pressure. The surface water is then drained.

Figure 4 is a general view of the Cerro Prieto, Mexico power plant. As of September 1973, it is reported that the plant attained its full capacity

Figure 3

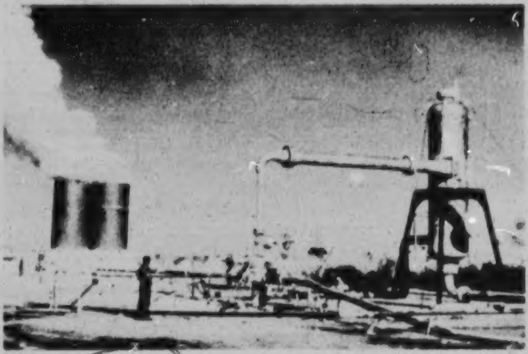

Figure 4

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[9] Budd, C. J.: "Steam Production at The Geysers Geothermal Field," and Finney, J. P.: "Design and Operation of The Geysers Power Plant," in *Geothermal Energy*, Kruger and Otte, *op. cit.*

[10] Courtesy of D. Anderson, Division of Oil & Gas, State of California.

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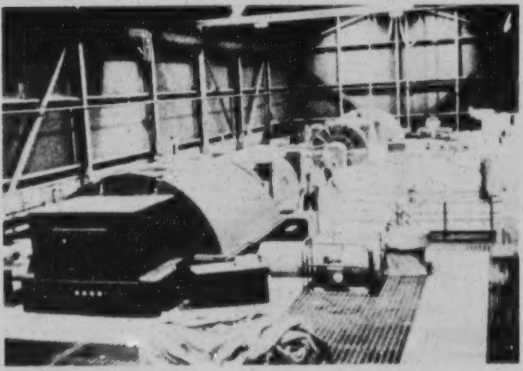
of 75,000 kilowatts. The dry steam and hot water plants are similar with respect to the construction of the power plant.

Figure 5 shows the turbine platform inside of a 110-megawatt plant at The Geysers (Units 5 and 6). Two 55-megawatt turbine generator sets are shown. The plants are reliable, and have little environmental impact in comparison to other thermo-electric power plants. Costs are extremely attractive. The cost of power generated by steam at The Geysers is about 60 per cent of that of power generated by competing fossil fuels.[11]

Many of the known hydrothermal systems do not produce clean fluids. Notable are the high salinity geothermal fluids of the Imperial Valley, Calif., and the bicarbonate geothermal reservoirs in Turkey.[12] Extreme deposition of calcite, corrosion, erosion, and numerous other problems have prevented development of electric power from these reservoirs.

Figure 5



Need for Utilization Technology Research

In addition to solving problems associated with "dirty" fluids, new drilling technologies are needed to permit deeper drilling into higher-temperature formations at lower cost. Also needed are well-stimulation techniques for economic production from low-permeability hydrothermal systems, and from impermeable, hot dry-rock formations. Hot dry-rock formations may be related to geothermal fluid systems in much the same way as shale oil is regarded by the petroleum industry. It is a question of when the secondary energy sources become economic to produce.

Binary-fluid cycle power plants such as the Magmamax[13] are expected to permit utilization of low temperature (less than 180° Centrigrade) brine reservoirs for power generation. This is accomplished by pumping the hot water out of the well and transferring the heat energy to a lower-boiling fluid by heat exchangers. This secondary "power fluid" is vaporized at high pressure, and the high-pressure vapor is used in a closed Rankine cycle to drive a gas-expander turbine connected to an electric generator. While such a system has yet to be demonstrated in this country, the Russians have been operating a 750 kW binary-fluid cycle plant using 90° Centigrade hot water with Freon as the "power fluid."[14]

Heat exchangers and gas-expander turbines have been used in industry for many years. The use of the binary system should not be dependent on development of large amounts of new equipment. It will require the ability to solve problems of controlling mineral deposition in heat exchangers, and in some cases, the extremely corrosive nature of the brines.

Groups are investigating the total-flow concept. This type of system would simplify plant construction a great deal in that the total fluid, steam and water, would be delivered to the turbine for recovery of power. Thereby would be eliminated the need for the steam separators and separate steam and hot water gathering lines.

Various segments of our industry have been carrying on research and development trying to develop new technology and equipment. But to have a timely development of this resource, we think there will be need to accelerate and expand our research programs.

RANN Geothermal Programs

Three major problems inhibit the development of geothermal resources today. The first is that of finding geothermal energy in sufficient concentration to justify economic development. This is a rather broad problem and involves all aspects of geology, geophysics, and geochemistry—the conventional exploratory activities that go into finding mineral resources.

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[11] *In The Matter of the Application of Pacific Gas and Electric Company Before the Public Utilities Commission of the State of California*, Application No. 53405, July 19, 1972.

[12] Koenig, J. B., *op. cit.*

[13] Rogers Engineering Co., Inc.: Magmamax Power Generating Plant Feasibility Study and Preliminary Cost Estimate, Magma Energy Inc., Los Angeles, Calif., 1970.

[14] Hibben, S. G.: *Soviet Geothermal Electric Power Engineering*, Advanced Research Projects Agency Order No. 1622-3, December 1972.

The second problem is more of an engineering matter. It involves the drilling of wells, the assessment of the quality of wells and the reservoir, and the mechanical and chemical engineering questions associated with utilizing the fluids that are produced above ground to generate electric power.

Finally, there is a broad range of problems involved in environmental issues, legal and political issues, and institutional problems. The National Science Foundation (RANN) programs are aimed in general to provide a concerted attack upon all three issues.

Of the RANN geothermal projects a few will be considered that illustrate the RANN principles involved. Figure 6 shows a lava pool in Mauna Ula Crater, the National Volcanic Park, on the Island of Hawaii, 1972. Lava fountains are evident, and the convective motion of the lava could be seen easily at the site. This volcano stayed active for over a year.

Two RANN Projects are in Hawaii. The first involved the drilling of a well near Kilauea Crater as proposed by Dr. George Keller of the Colorado School of Mines. In this project, a 4,000-foot well has been drilled for geological and geophysical purposes, and data is currently being evaluated and assessed.

The second project is at the University of Hawaii.[15] Dr. John Shupe is the principal investigator. This project typifies the sort of program that RANN has supported in several areas. It is an inter-disciplinary project aimed initially at locating sources of hot fluid on the Island of Hawaii. The next phase will involve drilling wells and is an engineering effort aimed at utilization of hot fluid in a broad sense. Finally, the program is aimed at investigating institutional, environmental and legal issues that would be associated with the development of a geothermal industry.

Figure 6

Another interesting project is at Marysville, Montana.[16] Dr. David Blackwell, of the Geophysics Department of Southern Methodist University, identified an area of very high heat flux. In one small drill hole, Dr. Blackwell found the heat flux to be ten times the normal average. Geophysical work conducted in Phase I of this project has identified a near-surface geothermal mass of approximately 100 cubic kilometers in size, shallow enough that it can be reached by drilling. The next phase is intended to involve drilling a well to determine just what this particular anomaly is. Rogers Engineering Co., Inc., San Francisco, will be responsible for drilling the deep test well.

Figure 7 shows the Stanford University Geothermal project well model.[17] This project is aimed at a study of well stimulation, and assessment of boiling flow through porous rocks. This project is also inter-disciplinary, involving civil engineering through Dr. Kruger and the Stanford School of Earth Sciences through Dr. Ramey.

Conclusion

Figure 8 presents a view of the Italian geothermal steam fields where it all began 70 years ago. The bulk of modern technology actually has been accumulated in recent years, and there is a great deal known about this field. However, modern exploratory methods aimed at finding geothermal fluids where no surface evidence

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[15] Yuen, P., "Hawaii Geothermal Project, Engineering Program," in *The Hawaii Geothermal Project, Quarterly Progress Report No. 1*, June 1, 1973, through August 31, 1973, University of Hawaii, Honolulu, Hawaii, 1973, RANN Document No. NSF/RA/N-73-113, and subsequent reports of that project.

[16] Stewart, D. H.; Kuwada, J. T.; Blackwell, D. [illegible] and Duff, R. E., *The Marysville, Montana, Geothermal Project, Preliminary Report*, Battelle-Northwest, Richland, Wash., Prime Contractor; Rogers Engineering Co., San Francisco, Calif.; Southern Methodist University, Dallas, Tex., and Systems Science and Software, La Jolla, Calif., November 12, 1973, RANN Document No. NSF/RA/N-73-114.

[17] Kruger, P., and Ramey, H. J., *Stimulation of Geothermal Aquifiers, Progress Report No. 1*, Stanford University, Stanford, Calif., March 1973, RANN Document No. NSF/RA/N-73-112. Ramey, H. J., Kruger, P., and Raghavon, R., "Explosive Stimulation of Hydrothermal Reservoirs," in Kruger, P., and Otte, C., eds., *Geothermal Energy*, Stanford University Press, 1973, p. 234.

Figure 7

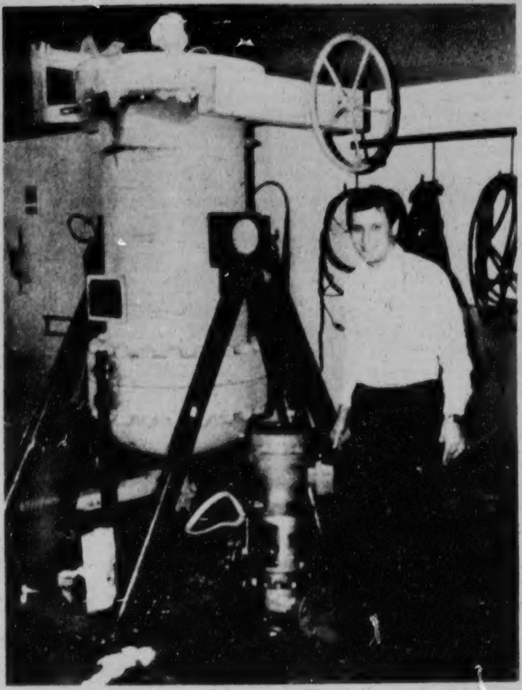

Figure 8

exist have been employed only recently in Italy as well as the rest of the world. This effort has led to the discovery of one of the biggest geothermal wells in the world. The well has a pressure of 60 atmospheres and would produce some 700,000 pounds an hour of steam. This well was viewed during a recent Joint USA-Italy Geothermal Seminar.[18] Returning to Figure 8, this view is typical of the Italian countryside in geothermal productive areas as they appear currently. The Italian geothermal industry involves many fields and perhaps 400 wells. It is nestled in a pastoral setting. The vineyards thrive, the sheep flocks multiply and, in general, the effect is a pleasing combination of electric power generation with an attractive environment.

Finally, we would like to comment that for present development of geothermal power to move to meet national needs, much attention must be given to legal, political and institutional problems. If geothermal energy is to be developed on an aggressive basis, it needs incentives for development, at least equal to those for development of oil, gas, coal, and other energy sources. This is such a new business that astonishingly few ground rules exist.

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[18] Personal observation, H. J. R., Pisa, previously cited.

WIND ENERGY CONVERSION

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Can the energy in the winds be utilized to help meet our nation's energy needs? That is the primary question to be answered concerning a very old, but presently little-used, source of energy.

Wind energy has several advantages that make it worthy of a reevaluation as a potential energy source. These advantages include:

1. Wind energy is a free, clean, non-depleting energy source. Wind is a form of solar energy that nature concentrates in certain areas and allows us to capture without using a large amount of land area.
2. Preliminary estimates indicate that wind could supply a significant amount of our electrical requirements.[1]
3. Utilizing energy from the wind is technically feasible; this is discussed more in detail below.

The disadvantages of wind energy include its variability and the high systems costs of past efforts. On an hourly or daily basis, the winds are not dependable. But on a monthly and yearly average the winds are a rather firm energy source. Past experience has shown that wind energy systems have usually cost about two to five times more than fossil fuel systems on a basis of kilowatts per hour per year. However, now that fuels are becoming scarce and conventional fuel costs have increased it is important to re-examine wind energy to see if its variability and higher costs can be overcome.

First, wind generators are technically feasible. Many moderate sized machines have been built and tested, for example:

- **The Dutch have used wind generators for years to provide power for pumping water and grinding grain.**
- **The Russians have been investigating wind power and built a rather large machine in 1931.** This wind generator had a 100-foot diameter rotor on a 100-foot tower and delivered 100 kilowatts at a wind speed of 24 mph.
- **The Danes used wind as a major source for many years.** They built the Gedser Mill System in 1957 and operated it through 1968. This wind generator produced 200 kilowatts in a wind of 33 miles an hour with a rotor diameter of 79 feet and a tower height of 85 feet.
- **The English built several large wind generators.** One machine was the Enfield-Andreau, built in the early 1950's. This machine had a maximum output of 100 kilowatts. The rotor was 79 feet in diameter mounted on a 100-foot tall tower.
- **The Smith-Putnam machine was built in Vermont in 1941 and supplied power into the hydro-electric grid.** This wind generator was the largest ever built with a rating of 1.25 megawatts in a 30 mph wind from a 175 foot diameter rotor on a 110 foot tower.
- **The Germans did some fine work in the 1950's and 60's under the direction of Dr. Hutter.** Machines of 10 and 100 kilowatts were built and tested over this period. The machines used light fiberglass blades with a simple hollow pipe tower with guy wires. An interesting point of this design is that it delivered its rated output of 100 kilowatts at 18 miles an hour. At this wind speed, most of the other machines were just beginning to produce power. The German effort represents the most

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[1] NSF-NASA Solar Energy Panel, *Solar Energy as a National Resource*, University of Maryland, College Park, Md., December 1972, RANN Document No. NSF/RA/N-73-001, pp. 65-68.

modern work to date for machines of this size.

No large machines are in operation at present. However, several firms around the world are supplying wind generators in the range of 5 kilowatts or less.

Given that wind generators are technically feasible, the question can be asked: Why haven't they been more fully utilized? There appear to be several reasons:

1. The wind is variable and the wind generator by itself cannot always produce power on demand.
2. The costs of wind-generator systems have been high compared with those of fossil-fuel systems.
3. There have been no recent sustained development efforts.

As mentioned above, the wind is not dependable on a short-term basis. But on a monthly and yearly basis, the winds are fairly reliable.

Several options are available for reducing the effects of wind variability. These are:

1. Storage systems, including batteries, flywheels, pumped hydro-storage, compressed air, and electrolysis of water to hydrogen.
2. Connecting wind generators to small diesel-electric systems, which would save fuel and provide supplemental power.
3. Large wind systems connected to hydro-electric systems to provide base-load power. In such an arrangement the wind generators could supply power whenever the wind is blowing allowing water to be saved to be used as the wind drops off. Our hydro-electric systems are water limited and wind generators could increase the base load of the systems.
4. Wind generators connected in a large grid. These may prove practical for generating base-load power. Over a large area the wind may be always operating some percentage of the wind generators.

Studies are planned to assess these applications and to determine the cost goals for the wind-generator systems.

Several research areas must be included in a program for the development of wind as a practical energy source; these include:

1. Cost reduction of subsystems and components.
2. Wind characteristics to determine practical potential in the U.S., the wind regions and preferred sites.
3. User requirements including verification of site characteristics.
4. Legal, environmental, institutional and aesthetic issues.
5. Testing of larger and improved systems.

Some of the first steps in this program that need to be done are:

1. Design, build and test modern machines for actual applications. This will provide baseline information for assessing the potential of wind energy.
2. Determine actual power costs in realistic applications.
3. Identify subsystems and components that may be further reduced in cost.

The practical conversion of wind energy is a major part of the NSF Solar Energy Program. The NASA-Lewis Research Center has also been working in the area of wind conversion for the last year and a half. At the request of the Puerto Rican government, Lewis has agreed to perform a conceptual design of a wind generator for Puerto Rico. Puerto Rico has favorable winds and a rapidly increasing demand for electric power. Possibly, wind power may prove to be a valuable source of energy for Puerto Rico. The NASA will be participating in the overall NSF Wind Program, particularly in conversion systems in the size of 100 kilowatts and a megawatt. From these systems tests, it will be possible to make a realistic assessment of wind energy conversion systems costs, operating characteristics, and the potential for significant power production.

As its part of the program, NASA will be designing the 100-kilowatt system for test in 1975. This machine will be similar to the German design mentioned earlier. The design calls for a rotor of 125 feet in diameter mounted on a 125-foot tower. The machine is designed to provide its net output of 100 kilowatts in a wind velocity of 18 mph. The controls will be located in a remote control room at the base of the tower. The pitch of the rotor blades will be varied to maintain synchronous speed for the generator.

The 100-kilowatt system will provide baseline costs and needed operational experience. By 1976 additional 100-kilowatt field tests are planned in several locations of the country. In parallel with these projects, systems designs will begin this year for megawatt-size machines. The results of the 100-kilowatt tests and the Phase 0 applications and wind studies will help directly in the megawatt systems design. If these results are satisfactory, testing of a megawatt system is planned for 1976-77 with larger systems following.

Conclusion

In conclusion, the following points are relevant to the utilization of wind energy as a source to help meet our energy needs.

- **The utilization of wind energy is technically feasible.** This is evidenced by the many past demonstrations of wind generators.
- **A sustained development effort may result in wind-energy systems that are cost competitive with fossil-fuel systems.** The cost of energy from wind has been higher than from fossil fuels but it may become more economical if fossil fuels continue to rise in price.
- **The short-term unreliability of wind as an energy source because of its variability can be reduced by storage systems.** Other options are connecting wind generators to diesel and hydroelectric systems and dispersing them throughout the large grid network.
- **Wind energy appears to have the potential to meet a significant amount of our energy needs.** Like all other sources, it will not meet all our needs.

Wind energy is one of the clean, nondepleting energy sources that should be seriously investigated as a source to help meet our nation's energy needs.

SOLAR ENERGY-THERMAL CONVERSION

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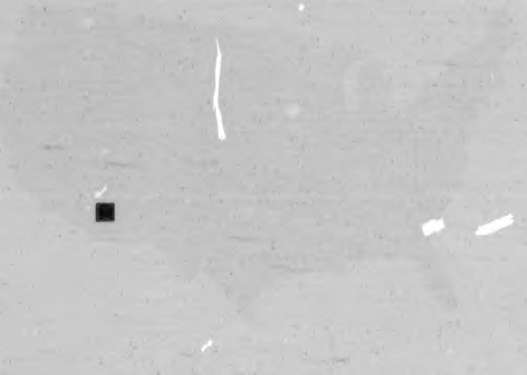
DR. ECKERT:

The sun provides us with a source of abundant, clean and safe energy in the form of radiation. Two statements demonstrate that it is abundant. First, the solar energy arriving as radiation on our globe in one or two weeks is equivalent to the energy contained in all fossil fuel reserves as we know them today. The second statement is illustrated in Figure 1. The black area shown on the map covers 1/500th of the area of the United States. Solar radiation impinging on this area would—when converted with 20 per cent efficiency—satisfy all our present needs for electric power.

Figure 1



On the other hand, some characteristics of solar energy have to be taken into account when an efficient solar-thermal plant is to be built. Solar energy arrives at the earth's surface intermittently. No energy arrives at night. It is strongly reduced on cloudy days. Therefore, a means of storing energy has to be provided or a solar plant has to be combined with another power plant—fossil or nuclear.

The solar energy flux is also rather diffuse. On a sunny day, approximately one kilowatt arrives at an area of one square meter (or 10 square feet) oriented perpendicularly to the sun's rays. One has to collect the radiation arriving from the sun over an area of some square kilometers or square miles to feed a solar-thermal power plant with a size from 100 to 1,000 megawatts.

Several means of collecting and concentrating the energy are available. Figure 2 is a schematic of a solar plant. A parabolic mirror or an array of plane mirrors concentrates the solar radiation optically on the surface of a pipe or a vessel. The radiation is absorbed there and converted to heat, which is picked up by a fluid and transported through pipes to a central spot. It is used there for heating or industrially or it is converted by a thermal power plant into electric energy. To different degrees, the various concepts of solar thermal plants supported by NSF-RANN or which are considered for support make use of optical concentration and collection by a fluid.

Figure 2

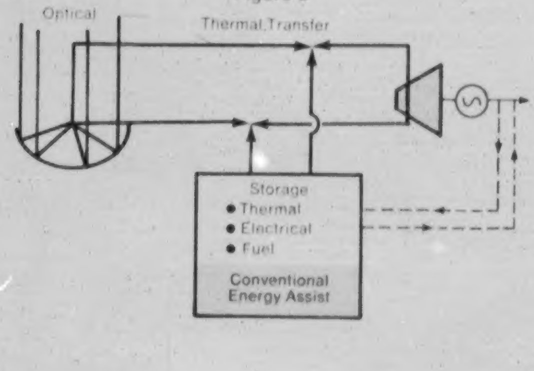


Figure 3 illustrates the solar tower concept, which uses optical concentration almost exclusively. The black rectangles in the figure indicate mirrors. A large number of those covers the field over which solar energy is collected. Each mirror reflects the solar radiation to the top of the tower, where it is absorbed and thus converted into heat and transported by a fluid to the base of the tower. This concept is being studied by the University of Houston with McDonnell Douglas. As a hybrid plant combined with a fossil power plant it is also proposed by Schjeldahl, together with the University of Minnesota and Foster-Wheeler. Combined with a hydroplant it is proposed by Martin-Marietta.

Figure 3

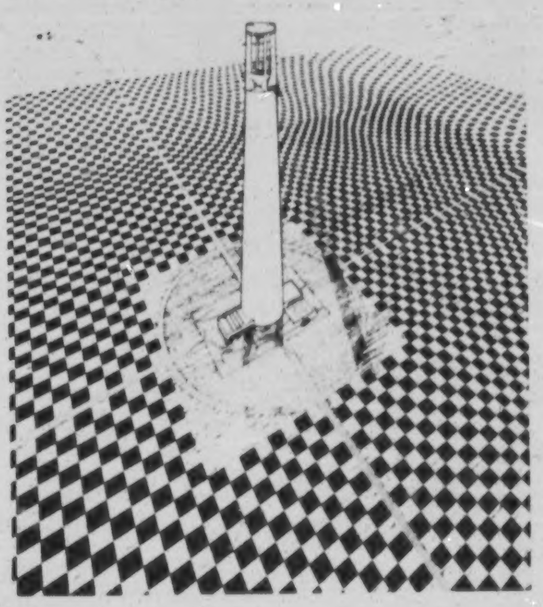
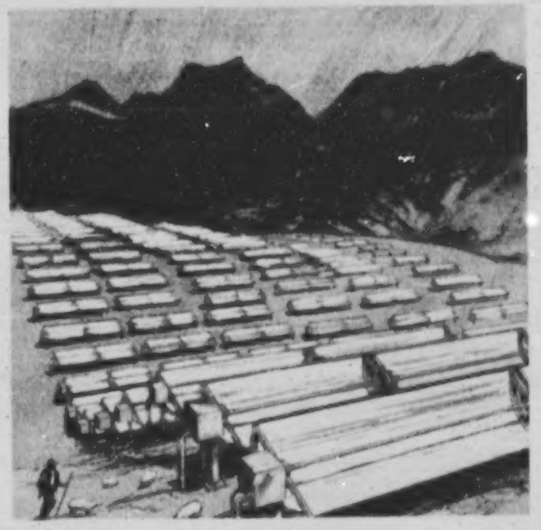


Figure 4 shows another design using parabolic mirrors, which again cover the collection field. They concentrate the solar radiation on the surface of pipes, where it is again absorbed and transported as heat by a network of pipe lines to a central location. This concept is being studied by the University of Minnesota with Honeywell. The parabolic mirrors can finally be replaced by plane absorbers, which again cover a field several square kilometers in size. The collection of the absorbed heat is accomplished by a transfer fluid.

Figure 4



This scheme is under study by the University of Arizona and Helio Associates.

Our present knowledge is insufficient to provide the basis for a comparison of costs of these concepts. Detailed analytical and experimental investigations are required to determine which is superior. It is also possible that the efficiency of each can be increased by the application of modern technology.

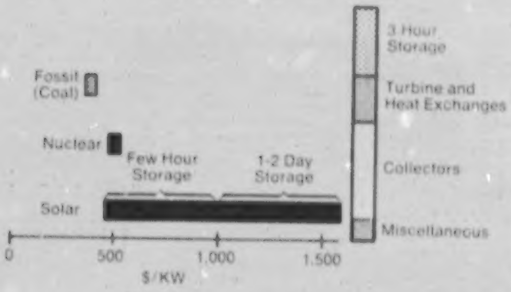
MR. SCHMIDT:

Most solar concepts were first presented years ago. For example, Figure 5 shows a photograph of the Shuman-Boys power plant that generated 50 horsepower from solar-heated steam in 1913. It happens to be a trough concept, but both the central-receiver and flat-plate concepts have been studied for some years on a limited basis. If these concepts are old, then why have they not been used before and why do we believe they now can be successful? Of course, the economic and other ramifications of the energy crisis have a large influence. But equally important are the new materials and new technologies we have to draw upon.

Shuman-Boys and solar power enthusiasts of more recent times did not have durable, selective, solar absorber coatings, nor heat pipes nor accurate pointing systems. All of these have been developed by the aerospace industry in recent years. Nor did they have the durable mirror coat-

Figure 5

Figure 6



ings and automated mass production we have today.

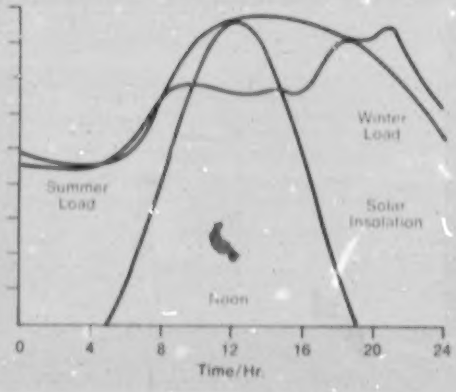
Low-temperature saturated steam turbines and high-temperature gas heat transfer have only recently been developed for use in the nuclear industry. These technologies and many more too numerous to mention improve the chances of reducing the cost of solar power to the point at which it is competitive with more conventional means. The major concern of solar thermal power is economics. How can we build a system that is competitive with conventional and alternate new sources of power?

Depending on the amount of energy storage required, and whose cost estimates one uses, solar power plants are expected to cost anywhere from $500 to something over $1,500 per kilowatt. Nuclear plants being designed for construction in the late 1970s are expected to cost about $500 per kilowatt. Fossil-fuel plants, projected for the same period are expected to cost $400 per kilowatt.

A major cost of the solar thermal power plant is storage. Even as little as three hours' storage requires about 20 per cent of the power plant capital investment (Figure 6). Storage of one or two days adds considerably to the power plant costs.

With only three hours' storage, how can a solar power plant function over a daily cycle and cloudy weather? First, a solar plant will probably not stand alone. It will be integrated in a power grid with nuclear and fossil-fueled plants. As such, it may be possible to use the solar power plant as a load-following plant. Figure 7 shows how load and insolation coincide in summer and winter.

Figure 7



By this we mean the solar plant will generate power during the peak load periods of the day and year. There is a correlation between the weather conditions and a load on a utility—air conditioning being the major draining factor. For example, a recent study in Dallas showed that the utility load would drop 40 per cent if the temperature dropped from 105° to 85° Fahrenheit. Peak load is considerably more expensive for a utility to supply than base load power. Utilities often lose money supplying this peak load because it costs more to generate the power than regulations permit them to charge for it. Peaking is often done with gas or oil-fired turbines, which are expensive to operate.

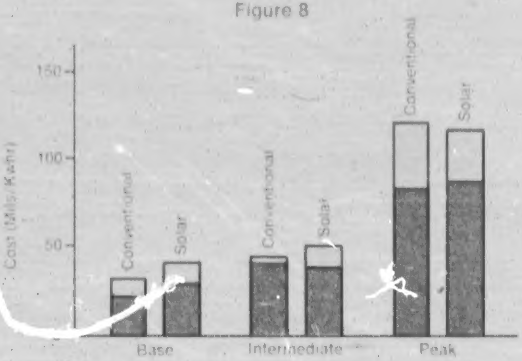
In a RANN study just completed by the Aerospace Corporation, it was found that solar thermal power has a higher probability of becoming cost-competitive with conventional power in the peaking and intermediate application than in a base load operation (Figure 8). In fact, it was found that by 1990 a solar plant would be competitive if the collector field costs could be held at $15 to $25 per square meter.

The bus-bar electrical cost is projected to be about 10 cents a kilowatt hour by 1990 for peaking purposes from both a solar and a conventional power plant. One reason the prospects for solar energy look good in this application is that it generates extra power that can be used in a non-peaking requirement just to save fuel. Pay-off credit can be taken for this fuel savings.

In summary, we must realize that solar power today is costly. The photons are free, but the equipment necessary to collect those free photons is expensive.

On the positive side, however, we have an abundance of solar technology to tap. With the proper use of U.S. capabilities and resources, we should be able to reduce the cost of solar power to a level that would be cost-competitive with conventional power by the last decade of this century.

Figure 8



SOLAR HEATING AND COOLING OF BUILDINGS—BACKGROUND AND ECONOMIC FACTORS

George O. G. Löf
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Director, Solar Energy Applications Laboratory
Colorado State University
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My role is to explain how buildings can be heated and cooled with solar energy. The purposes of this explanation are to provide a little background and the current state of technical development, to show the economic prospects, and to suggest ways of getting this technology into general use.

For many years, very modest effort has been applied to the investigation of the use of the sun's energy for the heating of buildings. More recently, solar cooling has received attention. Heating and cooling are technically feasible today. Depending on location in the United States and on the cost of other fuels, they are becoming economically attractive.

It should soon be possible to provide competitive heating and cooling from solar energy in about three-fourths of the United States. This estimate is based on use of simple technology already in existence to provide 60 to 90 per cent of a building's heating and cooling needs, and using auxiliary sources for the balance. The combination of heating and cooling makes the solar approach feasible today in many areas of the southern, central and even some northern sections of the country.

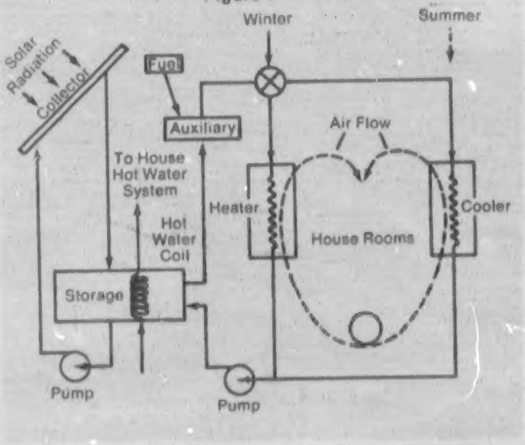
Further, the technology to be used is comparatively simple and available, but still experimental and primitive. The need is for some additional development and improvement, and the commitment of industry to mass-produce equipment at reasonable prices. Good starts in these areas are being made under the NSF-RANN program.

So where do we now stand in this field? Solar water heating is widely and successfully used in Australia, Japan, Israel and to a limited extent in Florida.

Up to the present, about 20 buildings have been heated partly by the sun. These experiments have provided useful data and have proved the technical feasibility of solar heating. One laboratory has been partially cooled by the sun operating an absorption air conditioner. The first full-scale solar cooled house is being designed only now at Colorado State University for completion in the NSF-RANN program early in 1974. While solar heating and cooling data are limited, and much more are needed, we know that there are no problems that cannot be solved.

A few of the buildings that have been particularly useful in advancing this technology are solar-heated experimental houses at the Massachusetts Institute of Technology in Cambridge, Mass.; Dover, Mass.; Lexington, Mass.; and Denver, and a solar heated and cooled experimental house at Colorado State University. Figure 1 is a schematic diagram of a solar heating and cooling system.

Figure 1



In the experimental system in my own 15-year-old solar heated house in Denver, air is the heat-collection medium. However, water will be used in the new solar heating and cooling system at Colorado State University. The water is heated during the day and stored for use at night and for short cloudy intervals.

A colleague and I recently have made an economic analysis of solar heating and cooling. We have found that in eight representative U.S. cities, these systems can provide solar energy for buildings at costs less than twice 1970 oil and gas costs. Table I contains a list of the principal variables used in this analysis.

Table I

CONDITIONS FOR PERFORMANCE AND COST ANALYSIS

A. *Data used*

For each of 8 cities (listed in Table II), 8760 hourly values (one complete year) of:

1. Atmospheric temperature.
2. Solar radiation on horizontal surface.
3. Solar position in sky.
4. Wind velocity.
5. Relative humidity.

B. *Design variables*

1. Two house sizes, 15,000 and 25,000 British thermal units (Btu) heating per degree day.
2. Collector sizes, 50 square feet to 2,000 square feet.
3. Collector slope angles, latitude minus 20° to latitude plus 30°.
4. Collector glazings, 1, 2, and 3.
5. Storage sizes, 2 to 40 pounds of water per square foot of collector.
6. Collector heat capacity, 0.2, 0.5 0.8 Btu per square foot per degree Fahrenheit.

C. *Cost bases*

Collector cost: $1.60, $2.00, and $2.40 per square foot for 1, 2, and 3 glass covers, resp.

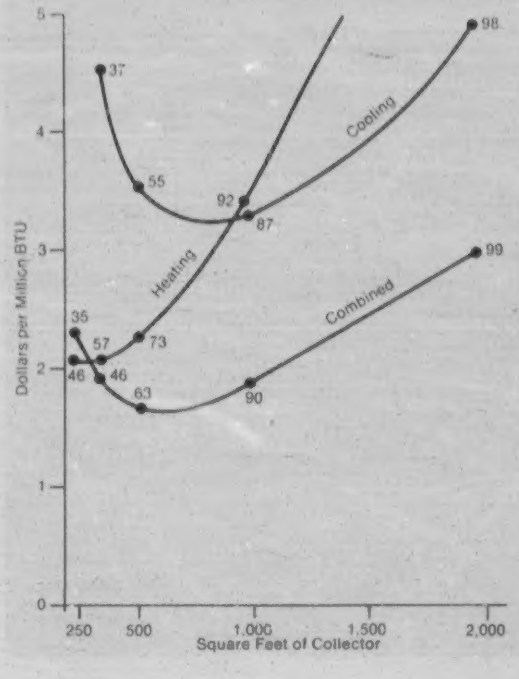
Storage costs: $0.05 per pound of water.

Other costs: $375 plus $1000 surcharge for absorption air conditioner.

Annual charges based on 20-year amortization at 8 per cent interest.

Figure 2 illustrates, as an example, the cost of solar heating and cooling in Albuquerque as affected by solar collector size. Table II shows the comparative costs of heating and cooling by solar and conventional sources in eight cities.

Figure 2—**Albuquerque**



In every case except Seattle, solar heat is cheaper than electric heat. In two locations, solar heat is competitive with fuel. In almost all locations, the addition of cooling decreases the cost of solar energy because of more continuous use of the same equipment. And even more important, we know that this energy source will become increasingly competitive as fossil fuels become more expensive.

That such increases have already taken place is evidenced by recent oil and propane prices. With fuel oil around 30 cents a gallon and propane at about 35 cents, the cost of delivered heat is now in the neighborhood of $3.80 and $5.80 per million Btu, respectively. Under the stated conditions, the cost of solar heat is seen to be substantially lower than these current liquid fuel prices at nearly all locations.

The conclusions indicated are based on several assumptions and estimates, the most important being solar collector costs of $2-4 per square foot—the latter being the approximate current price of Australian solar water heaters. The collector, representing most of the system cost, is a glass-covered black metal surface, with

Table II

COST OF SOLAR HEATING AND COOLING—$ PER MILLION BTU

	Oil or Gas	Electricity	Solar Heating	Solar Cooling	Solar Combined
Albuquerque	1.08	4.63	2.07	3.27	*1.73*
Miami	2.75 (oil)	4.87	>5.00	2.26	*2.13*
Charleston	1.14	4.22	3.34	3.50	*2.47*
Phoenix	0.94	5.07	2.86	2.05	*1.71*
Omaha	1.23	3.25	2.93	5.41	*2.48*
Boston	2.04	5.25	*3.02*	8.74	3.07
Santa Maria*	1.70	4.28	*1.57*	14.60	2.45
Seattle*	2.20	2.29	*3.15*	19.63	3.79

* One computation only

Design optima based on least cost solar heat for *purpose or purposes indicated* show minimum solar costs in each location.

Water heating included.

1970 fuel and electricity prices, adjusted for 56 per cent oil operating efficiency and 67 per cent gas operating efficiency.

Solar costs based on $2 per square foot collector, 20-year life, 8 per cent interest, $1000 surcharge for cooling.

Large house, heating demand = 25,000 Btu per degree day plus 25,000 Btu per day water heating.

SOURCE: Lof and Tybout, publication pending.

provision for passing a fluid in contact with it for heat transfer. Capital cost of the collector, storage, and all other system components are assumed to be amortized in 20 years at 8 per cent interest.

Several things will be required if solar systems are to be available for use in the near future.

First, industry will have to make an efficient solar heat collector available at prices below $4 per square foot. Cooling units specifically designed for efficient solar operation are also needed. The development and improvement of complete integrated systems of heating, cooling, water heating, and auxiliary energy supply must be accomplished.

Second, industry will need to undertake a major marketing effort to bring solar energy to the public. An important market will be in sales to commercial establishments where reduction in heating and cooling costs can be readily translated into economic benefits. Such establishments, many of which have large, flat roofs, are readily adaptable to this application.

Further, marketing efforts will be needed to show architects and builders the advantage of including solar systems in their construction plans for new dwellings. There is also the need to convince financing organizations that solar systems are eligible for inclusion in mortgages.

An additional market for solar systems will be in the retrofitting of existing buildings designed for fossil fuels. Both commercial and residential sectors are potential customers.

A major area of consideration is that of subsidies. If solar systems are to meet a substantial part of the country's growing fuel needs, they will have to appear soon, and be of low cost at the outset. This suggests needs for incentives to buyers or subsidies to manufacturers engaged in development and in the early stages of production.

If industry becomes active in the manufacture and sale of solar systems, and if incentives to the producer and the purchaser are adequate, it will soon be possible for solar energy to reduce the rate of increase of fossil-fuel demand. It is my firm opinion that demonstration and semi-commercial units can be available in two years, and that sales to the new construction market can begin within three years. In five years, there could be thousands of homes and businesses heated and cooled by solar energy. By 1985, there could be in existence a solar equipment industry of a billion dollars a year, saving hundreds of millions of fuel dollars.

I would not feel comfortable if I did not close with a word of caution. I have been active in this field longer than anyone in this country. I have seen a few successes and a lot of failures. I can assure you I have had my full share of the latter.

Nearly 20 years ago, there was a great wave of enthusiasm for solar energy development and use. Great optimism prevailed. Those who were somewhat skeptical were not believed by the enthusiasts. But time proved them right. The reaction to the overselling at that time set back solar technology.

So, let's not oversell again either by making promises we cannot keep or by rushing ahead with poorly conceived and inadequately engineered concepts.

We cannot afford failure in our effort to make this great energy resource available to all.

SOLAR HEATING AND COOLING OF BUILDINGS— RESULTS AND IMPLICATIONS OF THE DELAWARE EXPERIMENT

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University of Delaware
Newark, Delaware

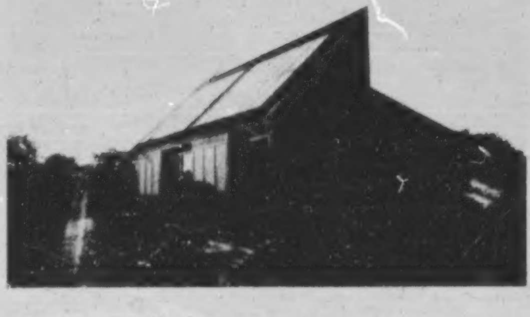
In looking to the time in the future when solar house systems can begin to reduce the fuel demand, one sees alternatives to low-temperature conditioning of air in residential and commercial spaces. When solar air conditioning is introduced, the first step will be taken to reduce the peaks of electrical demand that cause brownouts today and force us to use expensive fuel in our peaking power plants. New means of solar air conditioning are being developed. These means include new absorption systems, combined dessication and evaporation systems, and solar rankine engines driving conventional air conditioners.

The work done recently at the University of Delaware indicates that a major benefit could result from still another means to convert solar energy—the conversion of sunlight directly into electricity. Silicon solar cells have been in use for 15 years to power almost all of our space satellites. They are still very expensive but promising work is in progress to reduce this price dramatically. Not quite as efficient, but much less costly, are cadmium sulfide solar cells. Thinner than a human hair, they convert full sunshine into 50 watts of electric power per square meter of surface today, and a doubling of this output seems feasible within the next few years.

Such cadmium sulfide cells are currently producing heat and electricity to partially heat, cool and electrify a house called *Solar One*, on the University of Delaware campus at Newark (Figure 1).

In this house as shown in Figure 2 the panels on the roof contain cadmium sulfide solar cells to charge batteries in an adjacent shed and have air ducts behind these cells to conduct heated air to the basement for further use. The heated air from the roof panels is fed through a container as seen in Figure 3 to store heat at 120° Fahrenheit and to warm the rooms when it is needed. In inclement weather a heat pump amplifies lower-grade heat to make the house comfortable.

Figure 1



In summer the heat pump acts as an air conditioner. It runs mostly during night hours with off-peak electricity and stores coolness in a reservoir at 50° Fahrenheit. A small fan powered by solar cells moves room air through this reservoir and cools it comfortably. Even during the August heat wave the temperature in *Solar One* remained below a comfortable 73° Fahrenheit.

The electricity harvested through the solar cells is stored in a set of conventional automobile batteries and used for lights and stove. Other equipment and motors will be operated through inverters at 110 volts AC.

The roof contains 24 panels, which may be replaced at ease. A panel life of 15 years is expected. If one panel should fail, it would not affect the system's heating and would only slightly

Figure 2

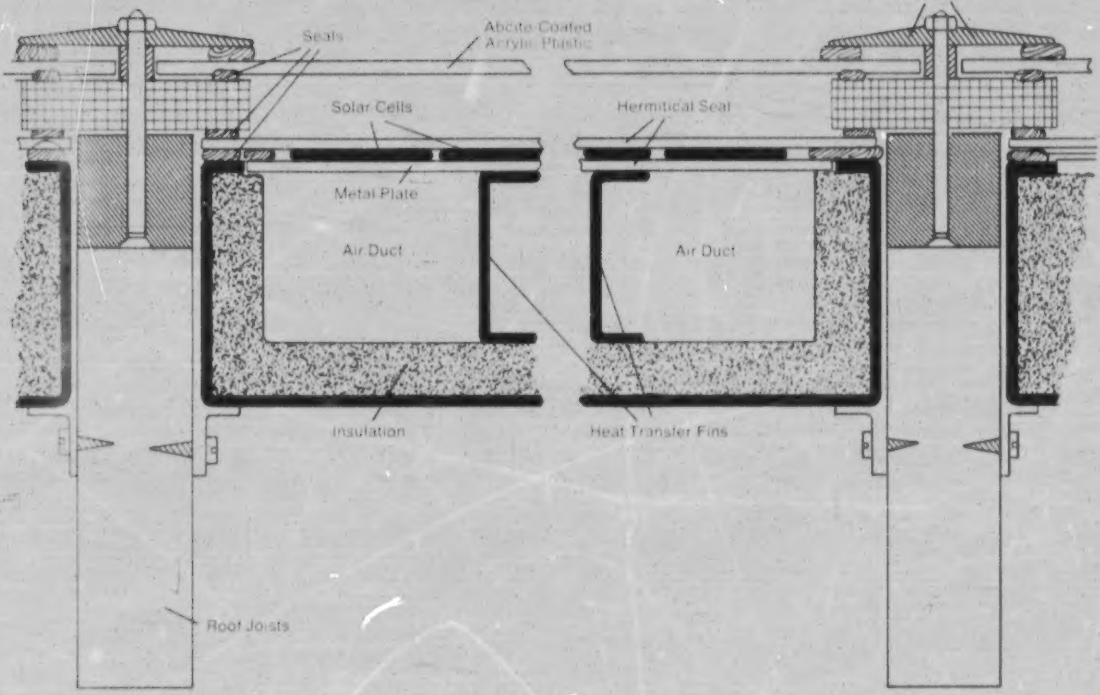

Seals
Abcite Coated Acrylic Plastic
Butyl Rubber
Solar Cells
Hermitical Seal
Metal Plate
Air Duct
Air Duct
Insulation
Heat Transfer Fins
Roof Joists

Figure 3

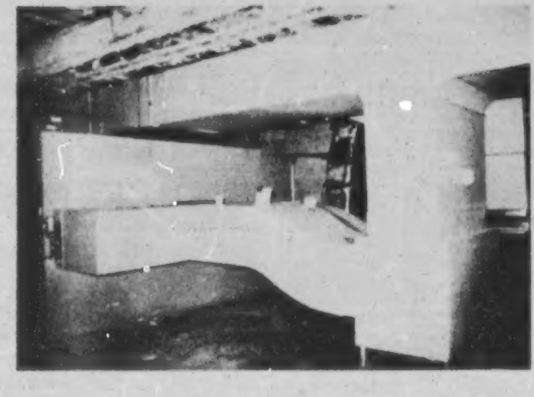
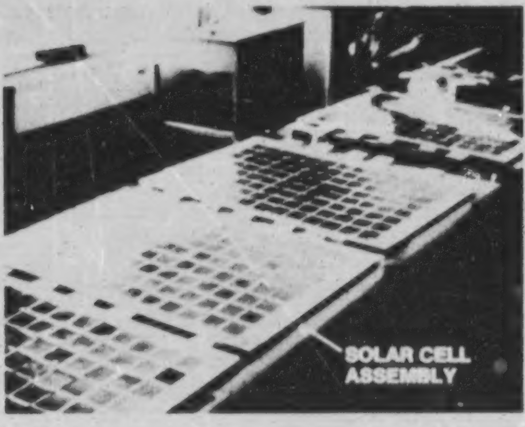


Figure 4


SOLAR CELL ASSEMBLY

alter the roof's electric power generation. It is a fail-safe system.

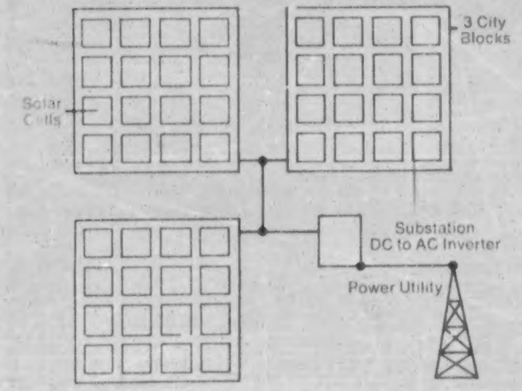
The key to the system is the cadmium sulfide solid state solar cell. At present we are preparing these cells in our laboratory as shown in Figure 4. But only a year from now we hope to have the first commercially fabricated cells available. The industry will need some years to develop proper mass-production technology. But with a concerted research effort, it is expected that such mass production can be achieved and the price per peak kilowatt of solar cells may drop below $200. No science and technology breakthrough is needed and the projected research and development effort is straightforward. The first steps of such research are now being sponsored by the NSF-RANN program.

Solar One is an example of use of the distributed energy of the sun converted at the place of the consumer. It shows that we can do it today with on-the-shelf components. *Solar One* is a house with an outside appearance only slightly different from traditional construction and an inside living space exactly like our current homes. When these components are mass produced we estimate that these houses could cost not more than 10 per cent more than conventional houses. Allowing a rate of 16 per cent for interest, amortization and other costs, solar heat and electricity could be available in most parts of the United States at a price comparable to that of conventional energy.

The idea of using solar energy as a distributed source has found resonance. A model suggested by Gildersleeve is the first to be offered by the power utility industry. It assumes a number of solar-cell arrays on commercial buildings and hooked into one inverter at a substation as shown in Figure 5. When the sun shines, this station adds power to the grid. It acts like a cycler plant and saves fuel.

How do we see the development in the United States? Solar conversion is feasible now, but to make a marked impact it must evolve from the stage of a hobby to serious, large-scale commercialization. One way to achieve this goal is to find a promoting and servicing industry—like the Bell System for the telephone. Power utilities are one possibility—and peak shaving is an obvious incentive.

Figure 5



The power demand on these utilities during night hours is low but during day hours has an uncomfortable peak. Figure 6 illustrates the marked relief that only a fraction of single-family houses covered with solar cells like *Solar One* could provide for the State of Delaware.

Peak shaving is achieved by using solar auxiliary power and load leveling as a result of nighttime air conditioning. Curve 1 on the figure represents load distribution during an average summer day in Delaware. Curve 2 shows solar energy harvested on 50,000 house roofs of 100 square meters with 6 per cent over-all conversion efficiency. Curve 3 is the difference between 1 and 2. Curve 4 represents modified solar energy supplies using minor electric energy storage techniques. Curve 5 is the difference between 1 and 4. Curve 6, then, is the resultant load distribution from nighttime air conditioning. With little additional storage the power utility hence can shed load at exactly peak times by disconnecting groups of solar powered houses from the grid sequentially. In addition, by using all their air conditioners at night times, as done in *Solar One*, almost perfect load leveling can be achieved —a major advantage for power utilities.

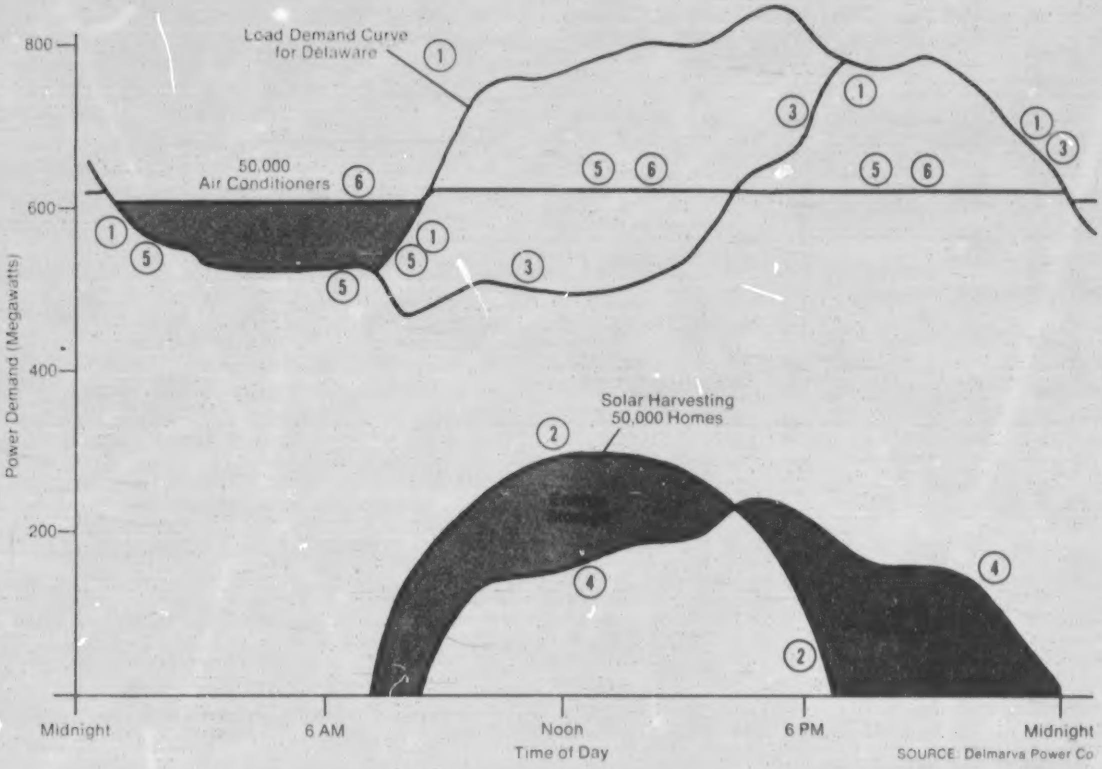
Are these advantages sufficient commercial incentive? Several power utilities have committed the first funds. Shell Oil Company has provided us with $3 million to begin initial commercialization. Other groups in the country have started to provide the first funds for their projects, and a major program in solar energy conversion is under way with NSF-RANN sponsorship.

But it is our belief that a concerted research effort will be needed to bring solar energy conversion to the stage of general acceptance. Better conversion and storage systems must be developed. We have to say that the cost of such research effort is commensurate with the cost of the development of other new markets. In high technology fields this can be estimated at about 10 per cent of the expected market volume.

For a multi-billion-dollar market, it cannot be expected that industry by itself can prime this research on the urgent time schedule that would be involved in meeting the present national need. In such cases, government action is required. The first signs of proper government action are visible. Much more needs to be done swiftly.

Within the next few years, it seems entirely possible that solar panels and small retrofit sys-

Figure 6



SOURCE: Delmarva Power Co

tems can be developed to reduce the conventional energy consumption of houses so equipped by 20 to 30 per cent. These systems may be produced economically and attractively. They may be expanded later to the more complete system described previously.

This potential of relatively fast relief of a substantial fraction of our energy demand in the space heating sector justifies the request for immediate major governmental funding. The long-range system including air conditioning and electrification offers proper means for final commercialization.

With sufficient support it seems to be the consensus of all in the field that large-scale terrestrial use of solar energy does not need to wait for 1989. As we made the 1960s the decade of the moon, we can make the 1970s the decade of the sun.

SOLAR HEATING AND COOLING OF BUILDINGS—PROBLEMS OF COMMERCIALIZATION

Lee L. Farnham
General Manager, Space Systems
General Electric Company
Valley Forge, Pennsylvania

John K. Stewart
Vice President,
Community Technology Corporation
TRW Systems
Redondo Beach, California

Nicholas V. Petrou
Vice President and General Manager
Defense Electronic Systems Center
Westinghouse Corporation
Baltimore, Maryland

MR. FARNHAM:

One of the important initiatives for increasing our supply of energy is the NSF-RANN program for fostering the wide-scale usage of solar energy for heating and cooling buildings. This importance is underscored by a National Science Foundation estimate that about one-third of the energy consumed today in the United States is used for heating and cooling purposes. Furthermore, the need of additional energy supplies, solar or otherwise, must be accomplished without unfavorable impact on our physical and social environments.

It is imperative, therefore, that a realistic assessment of the true potential of solar energy be made and, assuming a positive finding, the proper steps be taken to realize that potential.

As one of the world's leading companies supplying equipment and services for energy production and utilization, General Electric supports with enthusiasm the NSF-RANN program to achieve this objective. We are pleased and proud to be on the team.

Program Objectives and Structure

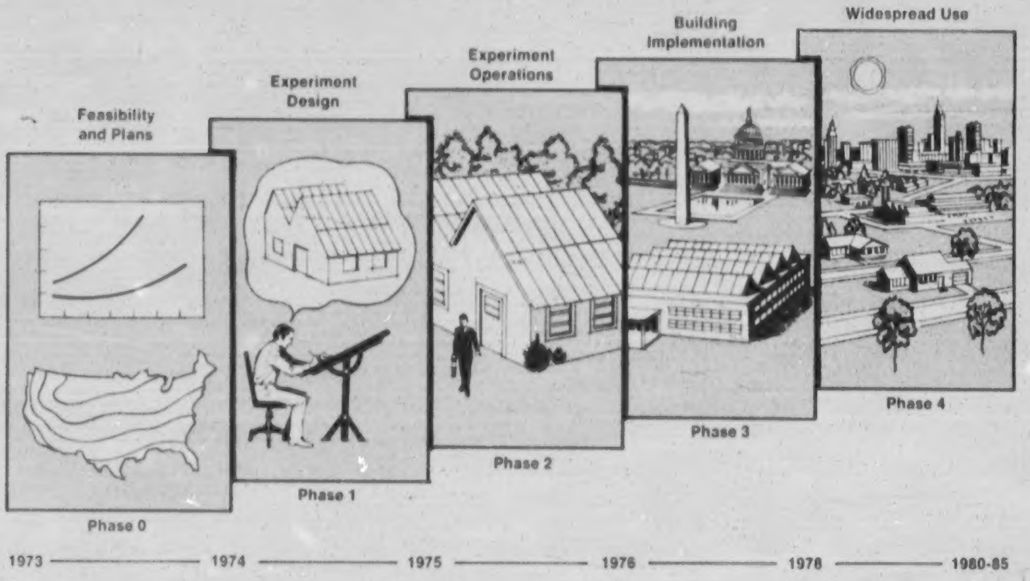
The NSF-RANN program is planned to use an expeditious, systematic approach—involving appropriate participation by government, universities, and industry, over the (1973-1985) time span, shown in Figure 1.

Phase 0 is already under way with contracts to General Electric, Westinghouse and TRW, each supported by universities that have been engaged in RANN-sponsored research in this field. GE is working in association with the University of Pennsylvania. This phase will define the technical, economic, societal and environmental barriers standing in the way of commercial acceptance of widespread application of solar energy for the heating and cooling of buildings. The intention is to develop strategies for overcoming these obstacles as well as designing action programs.

In the current phase, proof-on-concept experiments and supporting projects will be recommended and plans made for their execution. In both Phases 1 and 2, experiments will be designed, built and placed in operation.

After that, it is the announced intention of NSF-RANN to turn the government sponsorship of the program over to such mission-oriented agencies as Department of Housing and Urban Development, Department of Defense, Atomic Energy Commission, National Aeronautics and Space Administration, etc. Ultimately, the private sector will provide the equipment, distribution, installation, and servicing associated with the broad commercial application to buildings here and abroad.

Figure 1—**PROGRAM STRUCTURE**



Barrier Problems

Now let us take a look at the type of barriers which we face. They generally are similar to those encountered in the introduction of all major new approaches in the building industry. They fall into the categories of economic attractiveness; convenient, reliable performance; societal, environmental and aesthetic desirability, and legal safeguard. In one way or another, they all relate to fulfilling the needs and desires of consumers.

Proof-of-Concept Experiments

Proof-of-concept experiments are defined in Phase 0 and carried out in the subsequent two program phases. They will demonstrate technical performance, capital and operating costs, potential impact on energy consumption, public acceptance and engineering development requirements. They will give government, industrial and commercial leaders the needed evidence of practicality and provide the general public with a view of how solar energy can be increasingly important in their lives.

Dissemination and Utilization Plans

General Electric has been a major contributor to the development of new industries that have had major impacts on our national and international economies. We can say from experience that successful implementation of solar heating and cooling requires that we create a favorable awareness among all relevant segments of our society. Benefits such as economic savings must be communicated at all levels, ranging from the personal to the national. Techniques must be identified to minimize potential technical or economic risks. Government and industrial policy alternatives must be identified and evaluated.

It is essential that we provide the business climate needed to encourage manufacturers, architects and builders to provide and use the necessary equipment. This must be done simultaneously with or ahead of the development of equipment. And, most important, the public must be convinced to invest its money in the purchase of new products. All these actions are needed to assure that the widespread application of solar heating and cooling will be rapid and sustained, once practicality is demonstrated.

All of us are ready to respond to the President's challenge to successfully attain, by the end of this decade, the goal of "Project Independence" and make the United States totally independent in its supply of adequate energy. In the "spirit of Apollo," we can apply the lessons we learned in reaching the moon to harnessing the sun for the benefit of man.

MR. STEWART:

For those not familiar with TRW, we are a diversified company of about 85,000 people doing some $2 billion in annual sales in a wide range of products and services sold domestically and overseas to commercial and governmental customers. Part of the TRW family of organizations is its subsidiary, Community Technology Corporation, which is building and developing high-quality housing for low and moderate income families at a rate of $10-12 million annually. Residences are constructed using factory manufactured fully-finished modules or panels.

Over the last three years, we have participated in a program sponsored by the Department of Housing and Urban Development, intended to introduce new building materials and manufacturing processes to the construction industry. We have designed, developed and tested, and are now constructing some 500 townhouse and apartment units with a new building project called fiber-shell. This is made up of resin-impregnated honeycomb, glass-reinforced polyester resin facings and appropriate interior and exterior surfaces depending upon market requirements. A critical intermediate step in this process was a joint TRW-HUD program under which prototype dwellings were constructed using fiber-shell as a module for townhouses or single-family detached homes. Units were also built by on-site assembly of our panels along with other factory-built elements such as preplumbed wet walls to permit the builder to frame-in rapidly to a given floor plan and elevation. In the present NSF-RANN project, we are supported by Arizona State University.

This prototype program was oriented to the market in which the new technology would have to compete. In my conversations with NSF and other personnel regarding proof-of-concept activity on solar systems, I have noticed a strong focus on causing industry to "get to the market." In our view this is predominantly residential construction. I find this encouraging. In a proof-of-concept experiment, it is not enough only to answer the all-important question: is it technically feasible? Experimentation must also be designed to deal with some of the issues that will arise in the subsequent commercial implementation of a water heating and space heating and cooling solar system. For example:

- **Foremost, what are the economics?**
  - —What will the system cost?
  - —What is the relationship between increased down payment or first cost and financing?
  - —What is the probable increase in debt service?
  - —What depreciation schedule will apply?
  - —To what degree will there be lowered heating/cooling expense because of reduced fossil fuel consumption?
- **From the builder/developer's vantage point,**
  - —Do his heating, ventilating, air conditioning and framing subcontractors understand the system? What makes it work? How do they assemble it on-site?
  - —What design considerations does he and his architect have to take into account for the structure itself, the site layout, aesthetics and marketability?
  - —Warranties—who is responsible for what?
  - —Does it meet code?
- **The consumer asks about—**
  - —Continuity of operation?
  - —What it looks like?
  - —Operating costs?
  - —Insurance coverage for attractive nuisances, like a glass collector on the roof?
  - —Maintenance expense?
- **The infrastructure of the $35 billion residential construction industry needs to know—**
  - —What testing and evaluation programs must be successfully defined and carried out?
  - —What results must be accepted by FHA for federally insured mortgage programs and in general by the major code agencies?
  - —How can mortgagees make loan commitments which include capital costs of the system?

Our experience has been that the problem in introducing an invention, if you will, to the building industry is not the technology *per se*. Rather it is in understanding and successfully working with its myriad institutions, developing appropriate marketing and distribution strategies, and above all being competitive. This, in our judgment, is what we should emphasize in our proof-of-concept endeavors.

In closing, we are in hearty agreement with NSF's practical orientation and are guardedly optimistic about some general trends we perceive in our business.

In development, pressure for a new land ethic is growing. There is a shift from the concept of land as a commodity to one where land is a basic natural resource in which all citizens have a vested interest.

When a planned unit development is approved, an energy decision is made along with many others. Considering that water heating and space heating and cooling now account for approximately 25 per cent of the total energy consumed in the United States, it appears a question of time until criteria are established regarding the maximum amounts of fossil fuel which can be consumed for this purpose. Thus, public policy probably will assist in creating a market for solar energy systems particularly where fossil fuel is scarce and expensive.

MR. PETROU:

The use of energy, beginning with manpower and horsepower, and extending to nuclear power, has marked man's progress. Furthermore, man's ability to survive changing conditions has often been dependent on his quick adaptability to new forms of energy. Although such changes bring important benefits, they also impact on existing institutions. My brief discussion will focus on the anticipated benefits and impacts of solar systems.

The use of solar energy for some type of heating is not new. It is as old as the sun. What would be new is the development of solar building systems designed to conserve energy and efficiently use the solar energy available and to produce these systems on a large volume basis.

Efficient design and large-volume production are the keys to a system that will be economically competitive with existing systems, taking all other factors into consideration. As an energy affluent nation we have been wasteful of our fundamental resources. The designs of homes and buildings are often compromises of performance, aesthetics and costs. Very few have been designed to optimize for minimum heat loss. It is one of the considerations but seldom the dominant factor: witness the extensive use of large single pane glass panels.

A solar building must be considered as a system involving the intimate interaction of equipment, structure, orientation, location and aesthetics. Although it is easier to achieve an optimum design starting with the clean sheet of new construction, it should be possible to retrofit solar systems into that portion of existing buildings whose characteristics are suitable for the purpose. Retrofitting would provide the impetus to help achieve early widespread use of solar systems.

One of the most visible impacts of solar buildings is that they will be different and look different. Here is the challenge to not only the manufacturers but to architects, builders and developers. Solar buildings must be made attractive if they are to be acceptable. Clearly, unless that is done there will be great resistance by the consumer. And—to be sure—we are very sensitive to their views.

The new generation of solar buildings will impact on and have to be acceptable to equipment and construction codes.

Although we do not anticipate any serious problems, a comprehensive examination of building codes will be conducted and any potential conflict with the solar components and systems will be identified. Particular attention will be given to fire and safety requirements. This examination should yield recommendations useful to the code authorities.

Like codes, reliability of equipment performance under the full range of operating condition demands detailed consideration during the early design phase. The ultimate purpose of the NSF program leads to volume production. A component of marginal reliability can be a nuisance to the trained professional, but becomes a big headache when multiplied by large quantities. We must strive for simplicity, including simplicity of controls, as an inherent means of achieving reliability.

The problem with codes has been their great proliferation. Important progress toward unifying codes has been made in the past five years but a single code is still the Holy Grail beyond our grasp. Here is where we will need the full understanding and cooperation of state and local authorities.

We will need their help in zoning too. What may be one man's tall solar building pointing its collectors to embrace the sun's rays, may be a dark shadow to his neighbor, depriving him of not only light but the source of his heat. The concept and practice of 3-D zoning is not new but will take on added importance for solar communities. Not only relative heights of neighboring buildings, but orientation of each building is important in community design. If the solar collectors are integrated into the roof, the optimum solar building would face south and its roof would be inclined at an angle to maximize its sun's capture capability. Since the sun is higher in the sky in the summer than in the winter, a compromise angle of inclination would be based on the calculated savings achieved by heating and cooling, depending on the region of the country. These are simple examples of solar-associated problems that would stimulate the creativity of urban planners and architects and challenge the skills and adaptability of builders.

Initially at least, a solar building will cost more. This impact will be felt not only by the consumer but by builders and financial institutions. For a typical single family residence, it is estimated that the incremental costs may be a few thousand dollars. But the initial capital cost can be amortized by annual savings in the fuel, as I shall shortly indicate.

How to provide the capital for it is a challenge inviting innovative thinking by the government as well as the financial institutions. Recognizing that it is in the national interest to decrease dependence on fossil fuels—particularly imports of oil—the federal government may consider incentives to encourage the building of solar homes.

The use of solar energy will decrease the demand for oil in the winter and shave the high peak power demand created by conventional air-conditioning systems responding to the hot summer sun, thus easing the possible pain of blackouts or brownouts.

It is thus apparent that solar building systems will have extensive impact on the consumer, builder, architects, urban planner, financial institutions, public utilities and the federal and state and local governments.

There are important benefits that would justify meeting these impacts.

I have already indicated the benefits to the nation through a decreased dependence on fossil fuels. It has been estimated that such systems can save the equivalent of $180 million worth of gas and oil by 1985 and $3.5 billion by the year 2000.

The consumer too will benefit. How much depends on the future cost of coal, gas, oil or electricity. Dr. Löf, in an earlier paper (and who is associated with us on this contract with NSF), has carried out extensive calculations concerning the cost of heating *and* cooling of buildings by solar energy compared to oil or gas and electricity. These calculations were made for eight cities ranging from Albuquerque to Seattle.

The calculations indicate that for each million British thermal units (BTU) of energy, it would cost Bostonians $2.04 if gas were employed, $5.25 for electricity and $3.07 for solar energy. To say it another way, in Boston, solar systems (if they were available) would cost less than electricity today and it would take only 50 per cent increase in the cost of gas for it to equal the costs of solar systems. Looking ahead but a few years, such increases are not unlikely. Which brings us to the crucial point that solar energy will always be available as long as man survives: no one or no nation can turn off a solar valve.

Solar energy is as clean as it is abundant. For each pound of coal or gallon of oil or cubic foot of gas not burned, the atmosphere is spared the polluting gases they produce and discharge. There would be less heat pollution of rivers. Equally important is the conservation of our natural resources.

Sunshine on the roof is more quiet than combustion in a furnace. Nevertheless, the total noise of the other components such as fans, pumps and compressors should be lowered.

The nation, the consumer and the environment will benefit as will industry. In turn, industry has much to contribute.

In addition to considerable experience with the more conventional heating and cooling components and systems, industry offers the production capabilities essential to move solar systems from individual experimental units into widespread national use.

Westinghouse manufactures and markets conventional heating and cooling systems including heat pumps, and produces housing as well. Through our Coral Springs properties in Florida, we are developing large scale communities.

Designing of a solar building as a system optimized for energy conservation is important. We have already taken a step in that direction by designing the Electra III home there.

Electra III is expected to use 30 per cent less electricity than that required by similar sized all-electric homes in Florida without sacrificing comfort or convenience. The conservation is achieved through total architectural design and siting of the structure to take maximum advantage of sunlight, shadows, and natural breezes, improved insulation, extensive use of fluorescent and mercury vapor lamps and use of waste heat and solar energy to heat tap and pool water. We expect this home to be opened early in 1974.

We are most pleased to be part of NSF's comprehensive effort to stimulate and accelerate the creation of a national capability for solar energy utilization. We recognize that the purpose of NSF's program is to achieve widespread use of solar buildings within this decade. Although it starts with research and analysis, the program must proceed rapidly to system design and construction. The NSF program for Phase 0 through Phase 2 is well conceived and planned with a proper balance between urgency and reality. The conception and planning have recognized that the solar systems produced must not only perform as indicated but do so economically and reliably.

ENVIRONMENT

Threats to the Man-Made Environment

INTRODUCTION TO ENVIRONMENT PROGRAMS

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Washington, D. C.

Man has long struggled to combat the forces of nature and to live in harmony with them. Throughout human history we have had to live with the threat of potential catastrophe. Compared with the immense uncontrolled fury of hurricanes, earthquakes, floods, volcanic eruptions, fire and drought, the forces that man controls are puny and our social systems are fragile. Protection of the structures of man and of man himself from the destructive power of the hazards of nature involves not only the cost of the facilities and loss of human life but also conservation of our national efforts, resources and energy. A major hurricane, after all, has the energy of about 220 days' production of a large nuclear power plant. A major earthquake, such as that which occurred in Alaska in 1964 releases energy comparable to 63 years' output of such a power plant. A major flood can take thousands of lives and cause billions of dollars in property damage, to say nothing of the immeasurable cost and disruption of transportation, communications, and the normal course of human activity. These problems strike people around the globe.

A few weeks ago the headlines told of a massive earthquake in Mexico taking hundreds of lives, and of mammoth floods in Pakistan. More recently, a massive fire leveled a large part of Chelsea in Massachusetts. No agency or act of man could be expected to halt or really control such enormous phenomena. What research can do is try to find ways to minimize the cost in life and property, to warn, predict, prepare for and organize before disaster strikes, and to provide effective, equitable relief and repair during and after a catastrophe.

Essential Tasks

Scientific research can undertake four essential tasks to enhance the nation's ability to deal with disasters:

1. Assessment of existing knowledge and practice, how that knowledge is used, how present policies work, what insights can be gained from past experience, what knowledge can be provided and the likely consequences of policy alternatives for disaster relief.
2. Development of new socio-economic and policy alternatives—the analysis of the means society has at hand for reducing the human and economic costs of disasters, including research on policy implements such as regulation, insurance and planning to lessen the impact of these catastrophes and to allocate the costs equitably.
3. The development of new technological approaches to disaster mitigation including the prediction of impending disasters, measures of protection of life and property, design of structures to resist disasters and possible technologies for disaster prevention.
4. The development of a broader fundamental understanding: how and why disasters occur, the atmospheric physics behind hurricanes, the hydrology of floods, the geophysics of earthquakes, the dynamics of fire.

RANN Approach

These important tasks for research are essential elements of a well-designed national program. In the National Science Foundation programs, we support research directed toward each one of them. The basic-research component of NSF supports studies in the atmospheric and earth sciences that are aimed at developing a broader understanding of the processes and mechanisms of nature and their implications for disasters. The RANN program includes research on new technological approaches for disaster mitigation, particularly dealing with earthquakes and fire, which will be discussed by Drs. Hudson and Einhorn. It includes research on socio-economic and policy alternatives supported under the auspices of our Social Systems and Human Resources program. A detailed assessment of existing knowledge and practice in dealing with natural hazards is under way at the University of Colorado and will be discussed by Professor White.

DISASTER MITIGATION—EARTHQUAKE ENGINEERING

Donald E. Hudson
Professor, Earthquake Engineering
Research Laboratory
California Institute of Technology
Pasadena, California

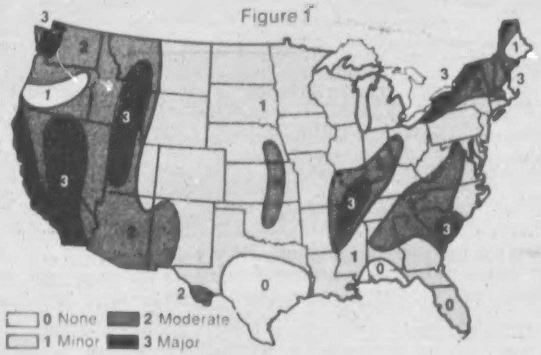
The objective of earthquake engineering is to prevent earthquakes from becoming disasters. Nature produces earthquakes, but man turns them into disasters.

If earthquakes could be prevented, the whole problem would be eliminated at one stroke. The earthquake engineer assumes, however, that earthquakes will continue to occur during the lifetime of his structures with about the same patterns of time and place as for the past few thousand years. He is aware of research aimed at control of crustal strain relief and of speculations as to the eventual control of earthquakes, but at present cannot justify abandoning his efforts to make structures safe against earthquakes.

From this point of view, the practical implications of earthquake forecasting come into focus. Even if an earthquake could be accurately predicted as to place, time, and magnitude, we still want to prevent disaster. Few of the earthquake engineer's problems would change with such forecasting. He would have new options to assess, but he would also have new uncertainties to grapple with as, for example, he balanced the hazards of an evacuation against the dangers of remaining in earthquake-resistant structures.

Although earthquakes are very unevenly distributed over both the world and the United States, we are dealing with a truly national problem. In Figure 1, the United States is divided into four zones: Zone 0 represents an absence of earthquake risk; Zone 3, the highest earthquake hazard. Twenty-one states have some territory within the Zone 3. An additional seventeen have some Zone 2 area. And, no state completely escapes Zone 1 region. About 30 million citizens live in Zone 3, and another 40 million in the moderate risk Zone 2. Although the problem is greater along the West Coast, the East Coast and the Central States also have significant high risk areas and have been subjected within historic times to major destructive earthquakes.

Figure 1



Hazards to Property and Humanity

The potential for economic loss can be judged from two recent events. The 1964 Alaska earthquake involved a loss of about one-half billion dollars, and the 1971 San Fernando, California, earthquake cost over one-half billion dollars. In each event favorable factors reduced the overall loss. The Alaska earthquake was large but occurred in a region of low population density. The California earthquake occurred near a region of high population density, but was small and occurred at a favorable time. If an earthquake approaching the size of the Alaska earthquake occurred in California, economic losses could run into many billions of dollars.

The nature of these economic losses and of the hazards to life and limb can be illustrated by the 1971 Southern California earthquake. A first example, in Figure 2, is the spectacular failure of an earth-filled dam. Fortunately, the water in the reservoir was at a reduced level at the time of the earthquake, so that the water was retained. Some 80,000 people living downstream of the reservoir were evacuated immediately after the earthquake. The nature of this near-catastrophe is terribly clear.

Collapsed freeway structures, such as that in Figure 3, were major features of the earthquake

Figure 2

Figure 3

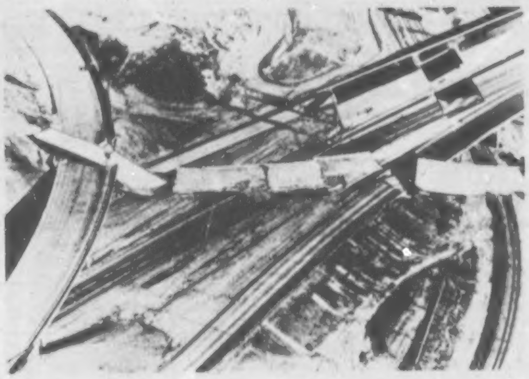


Figure 4

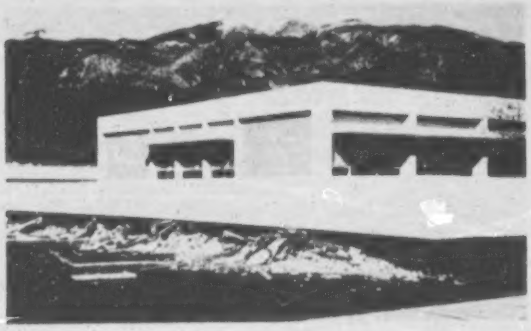
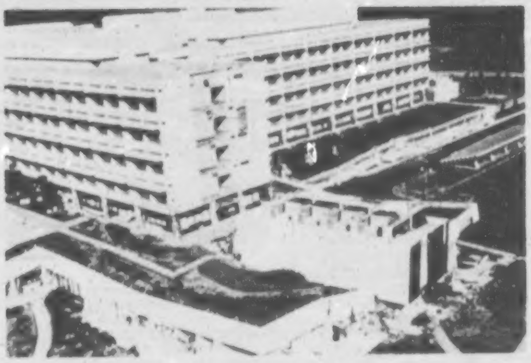


Figure 5



damage. At the 6 a.m. hour of the earthquake, traffic was fortunately light. The potential effects on peak-hour traffic are indeed frightening.

Building collapse, as in Figure 4, is illustrated by the failure of a new two-story hospital structure. The first story collapsed completely as a result of severe ground shaking.

Figure 5 indicates how heavily an adjacent hospital building also suffered. The stairwell structure at the right tipped over completely, crushing the lower floor beneath, and the whole first floor was almost at the point of collapse. This new $26 million building was a total loss and has since been razed. The design deficiencies which resulted in these failures have now been identified and code revisions have been made to insure against similar things happening again. However, we cannot be sure that the revised codes have anticipated all possible sources of trouble, or that they have achieved an optimum balance between safety and economy.

The effects of the earthquake on electrical installations at a key inter-tie station, such as that in Figure 6, form another impressive example. It is easy to imagine how such massive interruptions of electric power could disrupt modern urban society.

Figure 7 shows a classroom in an old school building some twenty miles from the epicenter of this relatively small earthquake. There a collapsed brick wall came through the ceiling, burying desks and chairs. Several hundred modern schools nearer the epicenter had no damage. The information and procedures needed to produce safe schools are clearly available, yet society still permits the use of old school structures which are known to be earthquake hazards. This points up the serious social and economic problems we face in the elimination of hazardous old structures.

The lessons to be learned from the above examples are clear. Earthquakes the size of the

Figure 6

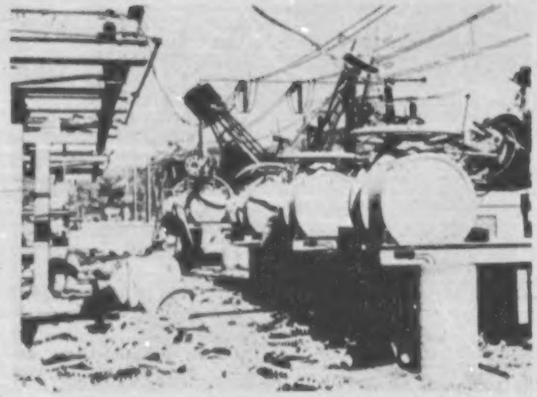


Figure 7

San Fernando earthquake are expected in Southern California about every five years. Some of them may be located in relatively unpopulated regions. But, some will be close enough to communities to pose major threats to human safety.

Application of Earthquake Engineering

Most of the recent advances in the practical applications of earthquake engineering to reduce hazards of the above types are based on fundamental research sponsored by the National Science Foundation. The way in which these research efforts have been organized is indicated by the following figures, which show the major elements of the program.

Figure 8 shows the broad divisions of the subject, and successive figures give the details of each.

The subject of strong-motion seismology described in Figure 9 supplies the basic information on destructive earthquake ground motion necessary to determine structural behavior.

Given the input ground motion, the behavior of engineering structures covered in Figure 10 can then be determined by means of structural dynamics, which in turn points the way towards proper design to resist earthquake forces.

The whole design process covered in Figure 11, however, must be constantly involved with the practical problems of economic construction, shown in Figure 12.

Finally, until we succeed in eliminating old hazardous structures built without regard to earthquake risk, the problems of disaster mitigation will remain, as outlined in Figure 13.

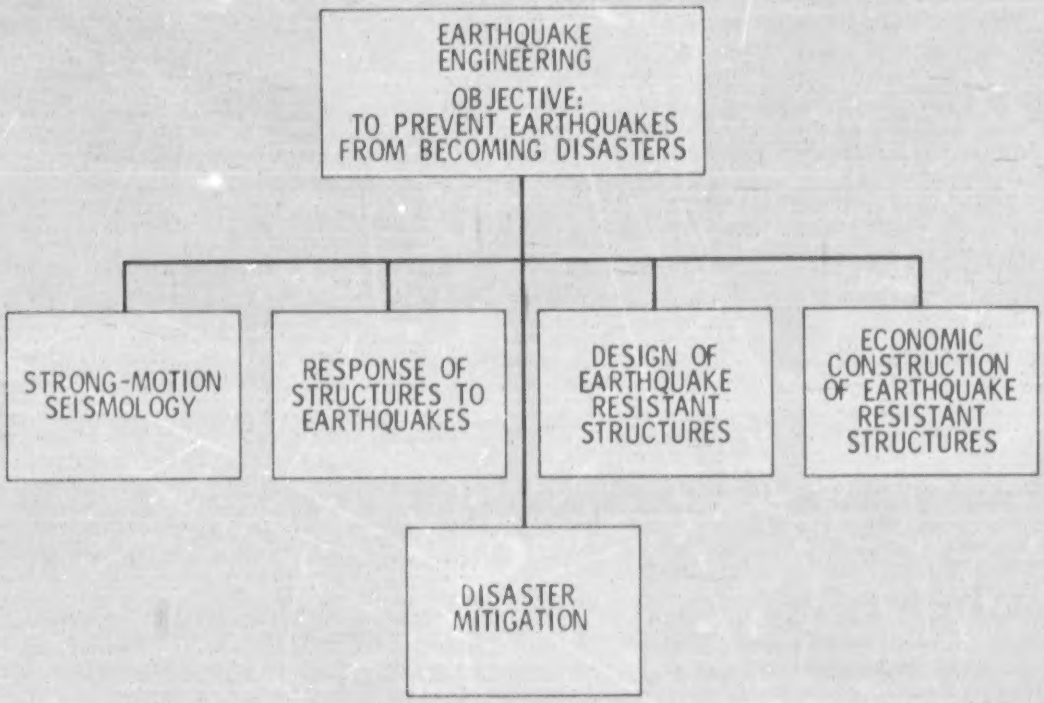
The accurate measurement of destructive earthquake ground motion is of special importance and has been cultivated almost exclusively by engineers. The network of strong-motion accelerographs developed and installed in the Los Angeles area with NSF backing produced hundreds of important records during the San Fernando earthquake of February 9, 1971, including the noteworthy accelerogram from Pacoima Dam, which showed peak accelerations twice as large as had previously been recorded anywhere in the world.

Concerning economic construction, the topic of codes and regulations is of prime importance. Here, again, NSF research has made direct contributions. It has been stated by the head of the Department of Building and Safety of the City of Los Angeles that it was the large number of measurements of actual earthquake motions in high-rise buildings obtained during the San Fernando earthquake that gave the city the confidence to advocate a new code based on dynamic design principles.

Dissemination of Research Results

The National Science Foundation has taken a number of practical steps to facilitate information transfer. In 1965 the Universities Council on Earthquake Engineering Research was organized under NSF sponsorship. It has arranged two comprehensive conferences aimed at coordinating research programs in the field and is now planning the third. An "Earthquake Engineering Research Digest" was issued in 1970 summarizing

Figure 8


EARTHQUAKE ENGINEERING
OBJECTIVE: TO PREVENT EARTHQUAKES FROM BECOMING DISASTERS
STRONG-MOTION SEISMOLOGY
RESPONSE OF STRUCTURES TO EARTHQUAKES
DESIGN OF EARTHQUAKE RESISTANT STRUCTURES
ECONOMIC CONSTRUCTION OF EARTHQUAKE RESISTANT STRUCTURES
DISASTER MITIGATION

earthquake engineering research projects of forty universities in the United States and Canada.

In 1971, NSF initiated the National Information Service for Earthquake Engineering, a joint program between the California Institute of Technology and the University of California at Berkeley.

Another notable NSF contribution was the sponsorship of a special committee of the National Academy of Engineering to carry out a comprehensive study of the field of Earthquake Engineering Research. The report of this committee, published in 1969 by the Academy of Sciences, has played an important role in the planning and coordination of many research activities.

One limiting factor in the utilization of new knowledge is the general level of education and training in the field. Fortunately, past NSF work in this field has centered in universities. By means of graduate courses, doctoral programs, extension courses, and specialized conferences and symposia, the universities can educate specialists and up-grade practicing engineers. Universities have also developed various avenues of communication with the public, thus facilitating general acceptance of regulatory planning. Nevertheless, qualified specialists in this field are in short supply, which limits the expansion of practical programs.

The NSF earthquake engineering program is a well-organized technical activity with considerable experience in developing new knowledge and applying it to practical goals. The successes of the program have been numerous but, considering the size of the economic stakes involved, past programs must be judged grossly inadequate. The need for a very substantial expansion of our efforts exists.

Figure 9

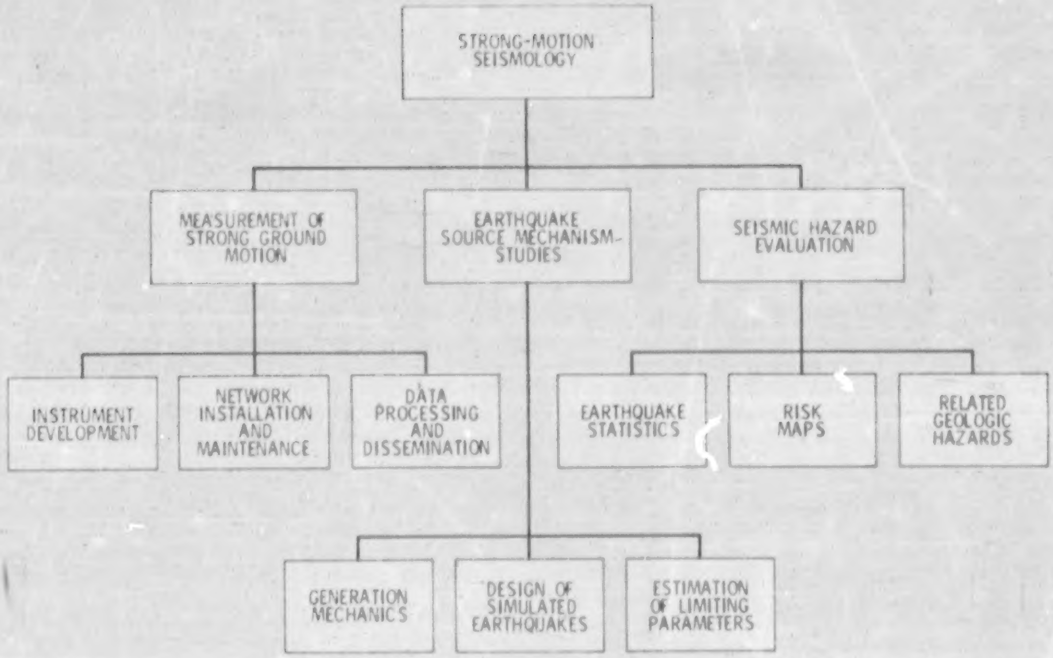

STRONG-MOTION SEISMOLOGY
MEASUREMENT OF STRONG GROUND MOTION
EARTHQUAKE SOURCE MECHANISM-STUDIES
SEISMIC HAZARD EVALUATION
INSTRUMENT DEVELOPMENT
NETWORK INSTALLATION AND MAINTENANCE
DATA PROCESSING AND DISSEMINATION
EARTHQUAKE STATISTICS
RISK MAPS
RELATED GEOLOGIC HAZARDS
GENERATION MECHANICS
DESIGN OF SIMULATED EARTHQUAKES
ESTIMATION OF LIMITING PARAMETERS

Figure 10

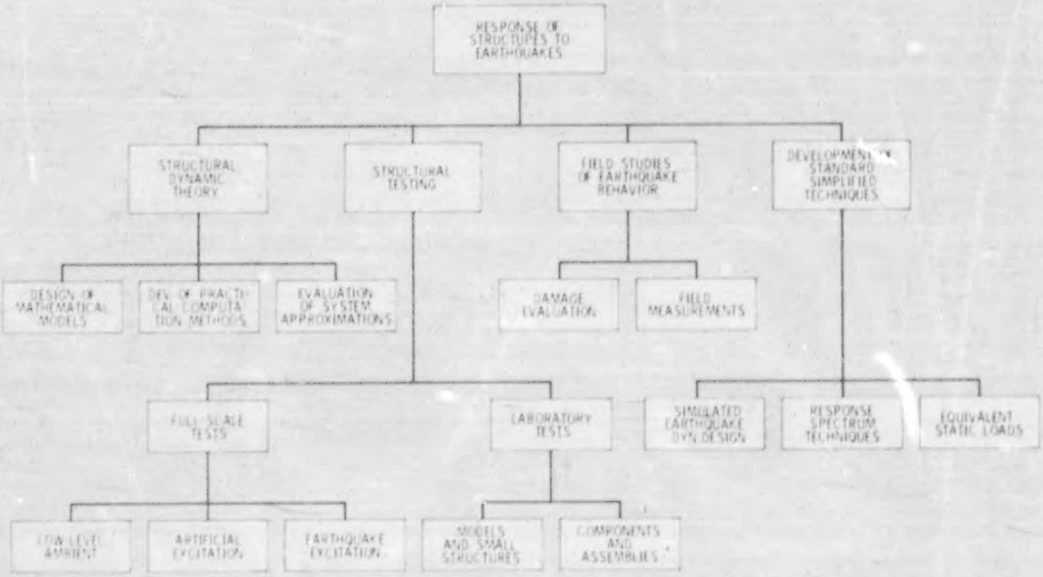

RESPONSE OF STRUCTURES TO EARTHQUAKES
STRUCTURAL DYNAMIC THEORY
STRUCTURAL TESTING
FIELD STUDIES OF EARTHQUAKE BEHAVIOR
DEVELOPMENT OF STANDARD SIMPLIFIED TECHNIQUES
DESIGN OF MATHEMATICAL MODELS
DEV. OF PRACTICAL COMPUTATION METHODS
EVALUATION OF SYSTEM APPROXIMATIONS
DAMAGE EVALUATION
FIELD MEASUREMENTS
FULL-SCALE TESTS
LABORATORY TESTS
SIMULATED EARTHQUAKE DYN.DESIGN
RESPONSE SPECTRUM TECHNIQUES
EQUIVALENT STATIC LOADS
LOW-LEVEL AMBIENT
ARTIFICIAL EXCITATION
EARTHQUAKE EXCITATION
MODELS AND SMALL STRUCTURES
COMPONENTS AND ASSEMBLIES

Figure 11

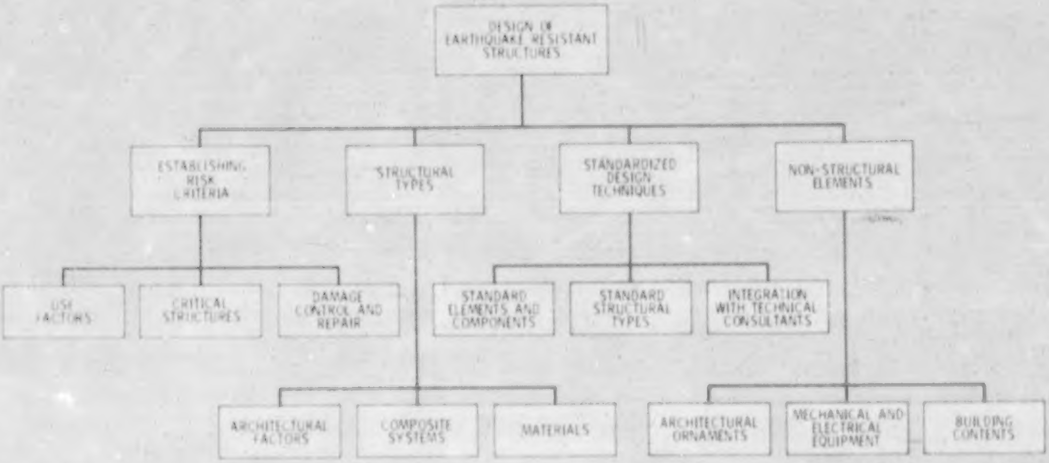

DESIGN OF EARTHQUAKE RESISTANT STRUCTURES
ESTABLISHING RISK CRITERIA
STRUCTURAL TYPES
STANDARDIZED DESIGN TECHNIQUES
NON-STRUCTURAL ELEMENTS
USE FACTORS
CRITICAL STRUCTURES
DAMAGE CONTROL AND REPAIR
STANDARD ELEMENTS AND COMPONENTS
STANDARD STRUCTURAL TYPES
INTEGRATION WITH TECHNICAL CONSULTANTS
ARCHITECTURAL FACTORS
COMPOSITE SYSTEMS
MATERIALS
ARCHITECTURAL ORNAMENTS
MECHANICAL AND ELECTRICAL EQUIPMENT
BUILDING CONTENTS

Figure 12

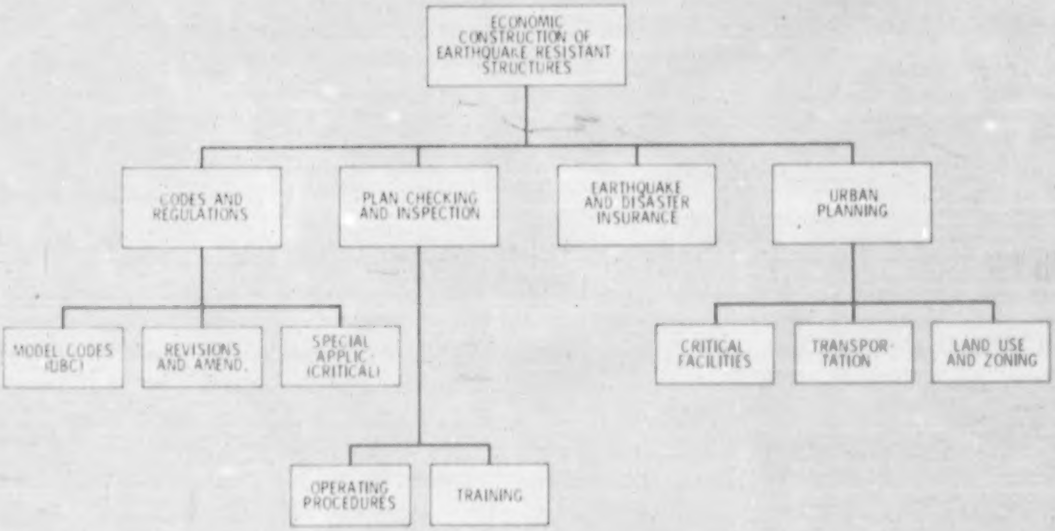
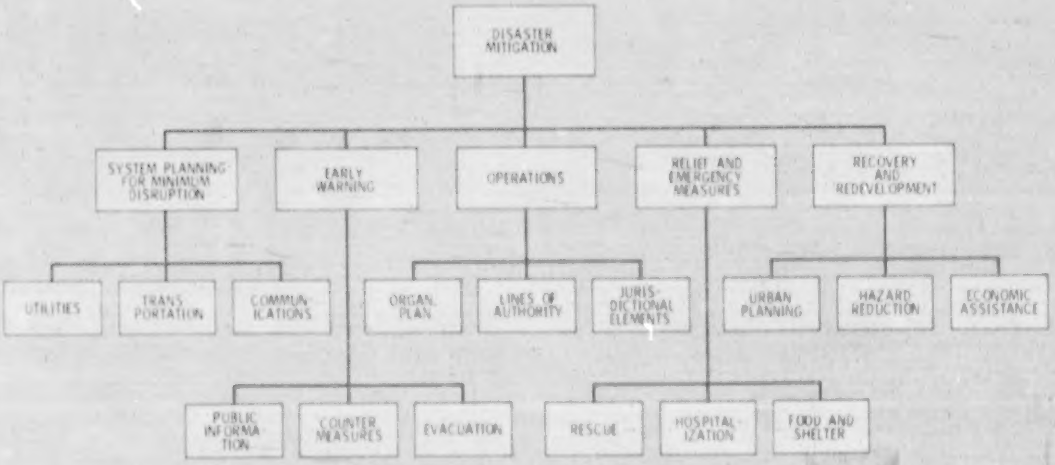

ECONOMIC CONSTRUCTION OF EARTHQUAKE RESISTANT STRUCTURES
CODES AND REGULATIONS
PLAN CHECKING AND INSPECTION
EARTHQUAKE AND DISASTER INSURANCE
URBAN PLANNING
MODEL CODES (UBC)
REVISIONS AND AMEND.
SPECIAL APPLIC. (CRITICAL)
CRITICAL FACILITIES
TRANSPORTATION
LAND USE AND ZONING
OPERATING PROCEDURES
TRAINING

Figure 13


DISASTER MITIGATION
SYSTEM PLANNING FOR MINIMUM DISRUPTION
EARLY WARNING
OPERATIONS
RELIEF AND EMERGENCY MEASURES
RECOVERY AND REDEVELOPMENT
UTILITIES
TRANS PORTATION
COMMUN-ICATIONS
ORGAN. PLAN
LINES OF AUTHORITY
JURIS-DICTIONAL ELEMENTS
URBAN PLANNING
HAZARD REDUCTION
ECONOMIC ASSISTANCE
PUBLIC INFORMA-TION
COUNTER MEASURES
EVACUATION
RESCUE
HOSPITAL-IZATION
FOOD AND SHELTER

DISASTER MITIGATION – FIRE RESEARCH

I. N. Einhorn
Flammability Research Center
The University of Utah
Salt Lake City, Utah

Per capita deaths and property losses attributed to fire in the United States exceed those of all industrialized nations by a factor ranging from 2:1 to 6:1. New synthetic materials for construction, draperies, rugs, comfort cushioning, and clothing, contribute significantly to these losses, injuries, and deaths—even though many of these materials are sold as "non-burning" or "self-extinguishing."

The 23 RANN studies for fire research range across a broad spectrum. They include:

> Methods to inhibit the undesirable characteristics of these materials during processing and fabrication.
>
> More realistic testing of their flammability characteristics.
>
> Analyzing the physiological and toxicological effects of the by-products of combustion or burning.
>
> Ways in which to fight fires more effectively and to treat fire victims more successfully.

Recent reviews of fire statistics[1,2,3,4] indicate that approximately 2.5 million fires occur in the United States annually, causing a property damage loss in excess of 2.5 billion dollars. Estimates of life lost on an annual basis exceed 12,000 with more than an additional 300,000 Americans injured each year. A conservative estimate of the total cost of unwanted fires is 11.4 billion dollars a year. Thus, the task of reducing this wasteful loss attributed to fire remains the major area of societal emphasis yet to receive national attention.

Historically small, uncoordinated fire programs, both research oriented and applied, have been sponsored by a number of agencies listed in Table I.

Table I

Organizations Supporting Fire Research

Bureau of Mines
Department of Defense
Department of Health, Education and Welfare
Department of Housing and Urban Development
Department of Transportation
Federal Aviation Administration
Food and Drug Administration
Forest Service
National Aeronautics and Space Administration
National Bureau of Standards
National Institutes of Health

The interagency organization, the Federal Fire Council, was assigned the function of coordinating the governmental programs in the fire research area. This council has been criticized as not effectively exercising its mandate. Thus, until quite recently, the national research effort directed toward solving the fire problem has been both small and fragmented. Conspicuously absent has been a National Fire Research Center, such as those long-established and comparatively well-financed programs existing in Canada, Great Britain, France, Germany, and in many of the Scandinavian countries.

For a number of years, the National Fire Protection Association, the Committee on Fire Research of the National Academy of Sciences/National Research Council, and the several groups

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[1] J. DiPietro, "An Overview of Flammability of Polymeric Materials—Yesterday, Today, and Tomorrow," University of Detroit, *Polymer Conference Series*—Flammability Characteristics of Polymeric Materials, Detroit, Michigan, June 16-20, 1969.

[2] I. N. Einhorn, "An Overview of Flammability of Materials," University of Utah, *Polymer Conference Series*—Flammability Characteristics of Polymeric Materials, Salt Lake City, Utah, June 15-20, 1970.

[3] *Fire Journal*, Vol. *64*, No. 5, September 1970, pp. 65-69.

[4] I. N. Einhorn, "Fabric-Related Injuries," University of Utah, *Polymer Conference Series*—Fire Prevention and Control—A Major Societal Problem, Salt Lake City, Utah, June 4-9, 1973.

within the National Bureau of Standards, have exerted leadership in the development and support of programs directed toward segments of the fire problem. The effectiveness of many well-conceived programs has been diminished by the lack of continuity of funding.

In 1970 the National Science Foundation, as part of what is now the RANN program, launched a large-scale well-coordinated fire research effort. The basic elements of the fire problem are summarized in Figure 1. This program encompasses the eight areas of research as listed in Table II.

Table II

NSF-RANN Supported Areas of Fire Research

- Research Support to the Fire Services
- Basic Combustion Fundamentals
- Mechanisms of Fire Suppression
- Physiological and Toxicological Aspects of Combustion
- Analysis of Fire Injury
- Fire Loss Reduction—Structures and the Built Environment
- Fire Loss Reduction—Fabric-Related Injury
- Fire Loss Reduction—Natural Resources

The NSF role in fire research is dependent on and complementary to the activities and interests of mission agencies, particularly the National Bureau of Standards, the Department of Housing and Urban Development, the General Services Administration and the Forest Service. The research emphasis of the program is directed at the fire problems of cities, where the losses occur, although some funds are used to support research that complements that of the Forest Service on forest fires. A third area of research support is directed toward fabric-related fire injuries. Within the scope of this presentation, coverage will be limited to the fire problems within our "built environment." However, this in no way detracts from the well-conceived and necessary NSF-supported fire programs in other areas of interest.

Research Designed to Assist the Fire Services

Etiology of Fire—Because of persistent inflation, the number of fires per thousand population is a more reliable measure of fire prevention than is the figure for dollar loss. Table III presents a summary of the number of fires that occurred in alternate years from 1961 through 1969.

Figure 1

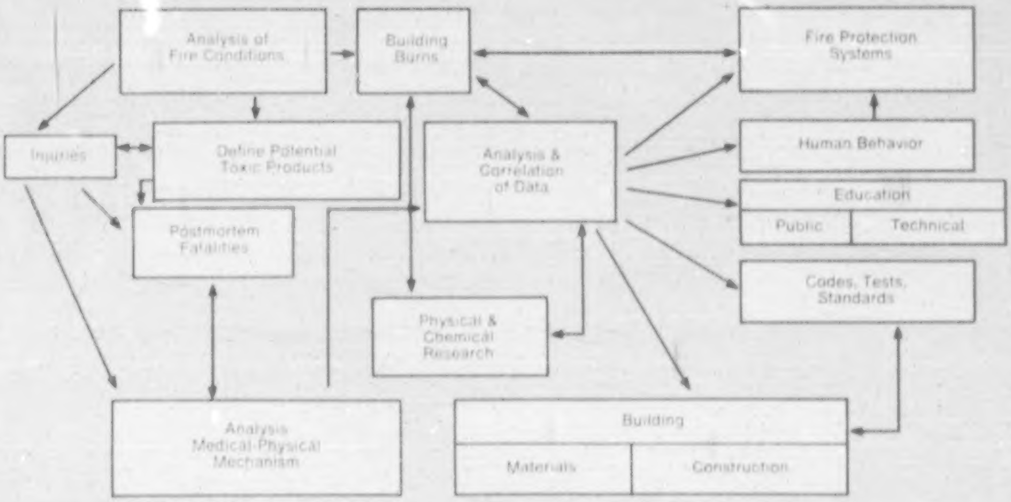

Analysis of Fire Conditions
Building Burns
Fire Protection Systems
Injuries
Define Potential Toxic Products
Analysis & Correlation of Data
Human Behavior
Education
Public
Technical
Postmortem Fatalities
Codes, Tests, Standards
Physical & Chemical Research
Analysis Medical-Physical Mechanism
Building
Materials
Construction

Table III

Annual Fire Statistics (Based on Population)*

Year	Fires Per 1,000 Population	Estimated Yearly Fire Losses
1961	12.0	$1,209,042,000
1963	13.1	1,405,558,000
1965	12.1	1,455,631,000
1967	12.1	1,829,920,000
1969	12.0	2,447,600,000

* From National Fire Protection Assn. data

Table IV presents a comparison between the percentage distribution of the chief fire causes in 1972 as compared with 1959.

Table IV

Trends in Fire Causes

Cause	1959	1972
Heating and Cooking	22.9%	16.0%
Smoking and Matches	18.0	12.0
Electrical	13.9	16.0
Flammable Liquid Fires and Explosions	6.5	7.0
Open Flames and Sparks	6.0	7.0
Lightning	3.3	2.0
Children and Matches	3.9	7.0
Exposures	2.8	2.0
Incendiary or Suspicious	2.3	7.0
Spontaneous Ignition	2.6	2.0
Miscellaneous, Known	11.3	2.0
Miscellaneous, Unknown	6.5	20.0
Totals:	100.0%	100.0%

Examination of this information offers an insight into the changing trends attributed as causes of unwanted fires. However, these statistics presented are derived from questionnaires sent by the National Fire Protection Association to the fire services in cities exceeding 50,000 population, which generally have the most efficient fire services. The total data bank represents approximately 60 percent of the population in the United States, so that a substantial error in the total number of fire injuries probably exists.

Programs at the Applied Physics Laboratory, The Johns Hopkins University; the University of California at Berkeley; and the University of Utah's Flammability Research Center, sponsored by NSF, have reported discrepancies in numbers and classifications of fires as a result of in-depth analysis of fires. Also, studies at the University of Utah's Flammability Research Center have indicated that as many as 35 per cent additional fires occur but are never reported through official channels. These studies have utilized the state and local fire services, the hospital emergency facilities and medical personnel in the Salt Lake Valley communities. As a result of long periods of hospitalization and rehabilitation, many delayed deaths resulting from fire injuries are not attributed to fire by hospital personnel.

Little precise information is available pertaining to the effect on fire origin of climatic conditions, such as temperature, humidity, wind, etc. The actual sequence of events and the nature of materials involved in fire origin and spread are often not reported by the fire services. The RANN studies, by the previously-mentioned centers, are attempting to correlate this much-needed information.

Evaluation of Special Hazards—Analysis of three major fires that occurred during 1970 reflects the special hazards introduced into the "built environment." These are a result of a combination of testing and evaluation procedures used to characterize the flammability characteristics of materials which do not relate to actual fire conditions. They are also a result of the improper use of certain classes of materials due to a lack of knowledge of the potential hazards.

The first fire considered had resulted in the deaths of 22 elderly persons at the Harmar House nursing home in Marietta, Ohio. This fire is believed to have been started by the careless ignition of materials in a polypropylene waste basket. It spread to a foam mattress, then to the nylon carpet, and to the carpet's foam underlay. Noxious black smoke hampered efforts to rescue those patients still trapped in the building. Those patients whose room doors had been opened by a nurse to facilitate evacuation were overcome by smoke. Those whose doors had not been opened, survived. Figures 2 and 3 illustrate a similar situation, which claimed the lives of six patients, during a fire a year later in the Lil-Haven Nursing Home in Salt Lake City.

Fire investigators reported that a foam mattress like the one in the room of fire origin "may fall into a blazing combustion that literally flashes (explodes combustively) and is consumed in a matter of minutes, giving off enormous volumes of heat, smoke, and toxic gases."

The second fire illustrating special hazards caused by materials occurred in a New York City

Figure 2

Figure 3

high-rise structure. J. T. O'Hagan, Chief of New York City's Fire Department, stated, "It was the first time that a fire in a high-rise fireproof structure spread with lighting speed to involve two floors and a total of 40,000 square feet before the arrival of the Fire Department." By the time the fire was extinguished, two men were dead and 30 others were hospitalized. Damages to the 50-story building exceeded $10 million.

The third fire under consideration, again involved foamed plastics. Within 30 minutes of the start of a fire in the British Overseas Airways Corp. terminal at Kennedy International Airport, New York City, the fire spread the entire length of the 330-foot structure, causing approximately $2.5 million in damage.

The parameters common to each of these three fires and representative of many more major conflagrations that have occurred throughout the world were examined in our studies. Consideration of these observations has led to the demand by the fire services for consideration of the fire "load" permitted in inhabited structures. The newer synthetic materials appear to have equal flammability characteristics when compared to the more conventional construction materials, such as wood. But they respond differently to a potential ignition source. For example, once ignited, some of these synthetic materials propagate with considerable speed and heat intensity build-up. They release highly combustible degradation products, usually accompanied by heavy smoke production.

Several NSF-RANN programs have plans designed to develop the means of predicting and controlling this hazard. The next two figures schematically represent the corner test being developed at the University of California at Berkeley and at the Factory Mutual Research Corporation, to evaluate the ignition and flash-over characteristics of building materials. Figure 4 shows the early flame spread and Figure 5 the flash over.

The next two figures are sequential photographs that illustrate "flash over" characteristics of rigid, fire-retarded polyurethane foam speci-

Figure 4

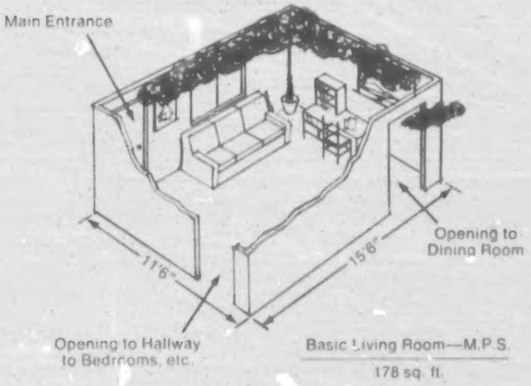
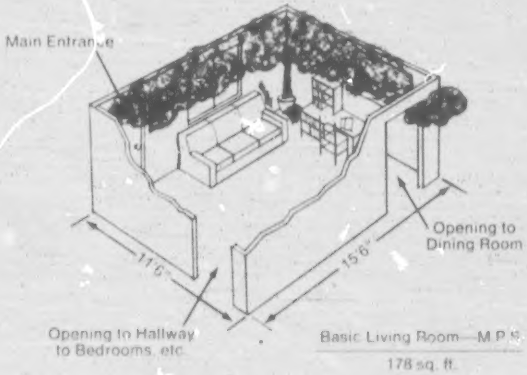


Figure 5



mens. Figure 6 shows a corner test 4 minutes after ignition; Figure 7 is after 10 minutes. Analysis of numerous large fires involving this class of materials has resulted in the promulgation of more realistic code requirements for foamed plastics specified in building applications. This standard has resulted from a cooperative effort involving building code officials, the material suppliers, The Society of the Plastics Industry, Inc., fire officials in the State of Utah, and personnel of the NSF-RANN-sponsored program located at the Flammability Research Center of the University of Utah.

Fire Department Tactics—In the past, the effectiveness of fire control depended solely upon the training of the firefighting services employed and the director of the fire combat command. The program sponsored by NSF-RANN at The Johns Hopkins University's Applied Physics Laboratory has included the development of a command and control kit (Figure 8), which can be carried to the fire scene.

Figure 6

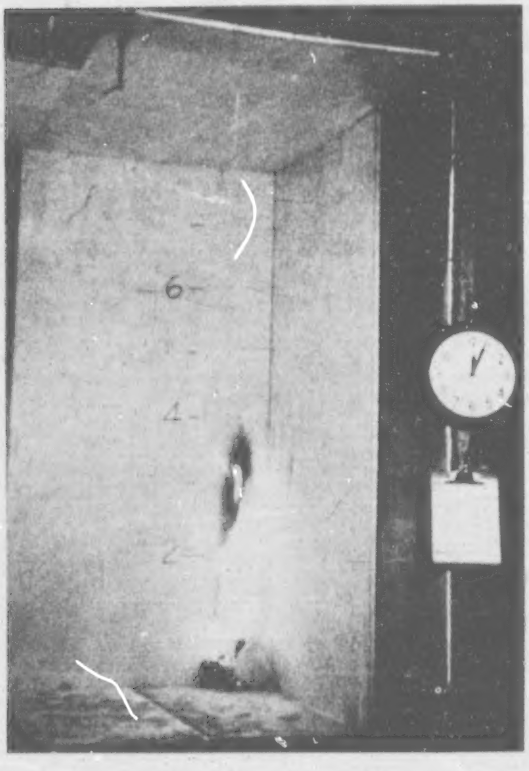
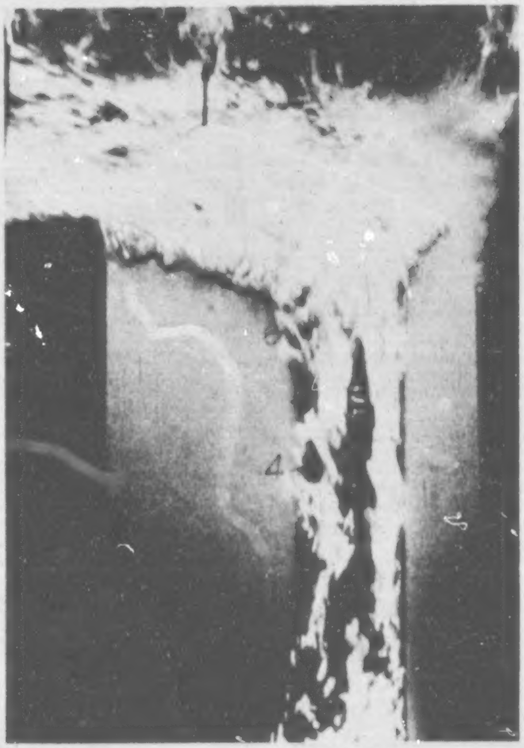


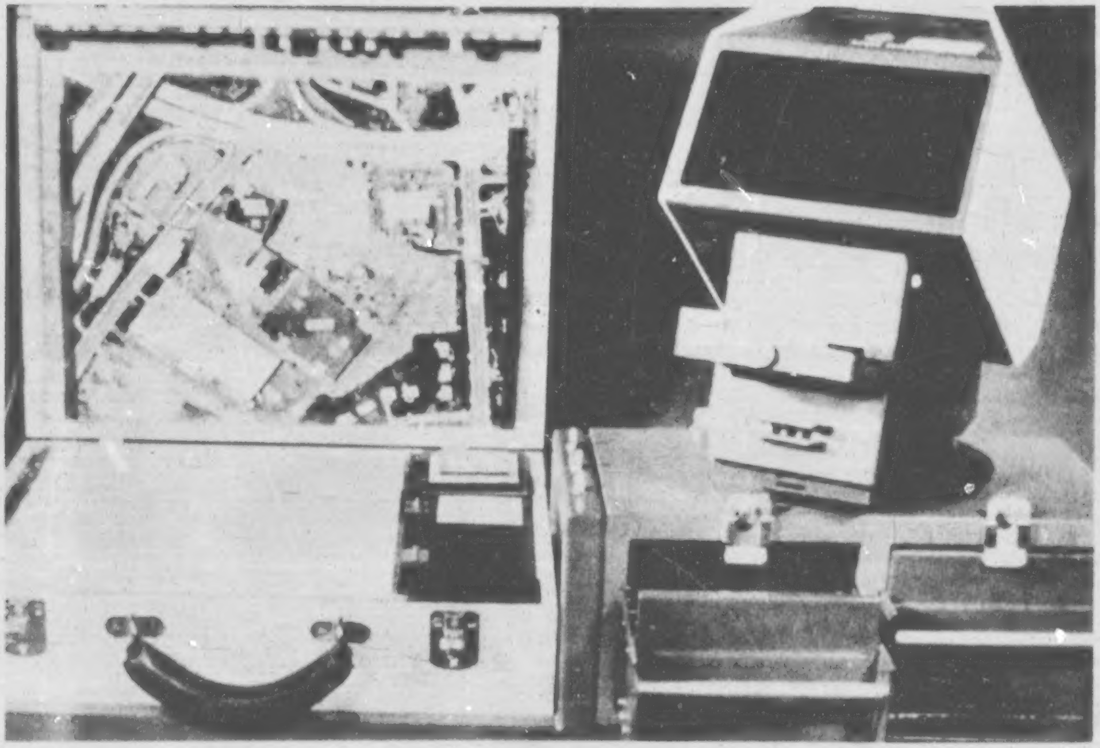
Figure 7



The kit's key components are aerial photographs of places within the fire company's response area where loss of life or property could be extensive: shopping centers, schools, nursing homes, hospitals and large office or apartment complexes. These photographs show the location of hydrants, cutoffs for natural gas and electricity, and other pertinent information necessary for effective fire control. Additional information covering both men and equipment may be recorded on a situation event log so as to permit instantaneous review of the fire and the firefighting resources. This fire management systems approach is presently being evaluated as a prototype system in Maryland.

Improved On-Scene Medical Treatment—A few definitive studies have been reported in the literature pertaining to smoke and its effect on humans during and after fire exposure.[5,6,7] These studies indicate that respiratory tract damage is "a principal killer" in fire victims. To reduce the incidence of death and the development of per-

Figure 8



manent neuropathy, rapid treatment of the fire victim is necessary, commencing at the fire scene.

Pilot experiments have been undertaken by Utah researchers under NSF-RANN sponsorship to investigate the protective action of steroid hormones and allopurinol (xanthine oxidase inhibitor) on animals exposed to carbon monoxide. Both acute and long-term effects of CO are being assessed. The effect of shock on carbon monoxide intoxication will also be studied in an attempt to develop more effective initial treatment of fire victims.

Educational Programs—An important aspect of the educational phase related to fire research activities is the development and wide dissemination of information via television, radio, newspapers, or appropriate scientific journals. Each of the NSF-RANN-supported research programs is designed to close the research-into-practice loop. In addition, symposiums and conferences are held for the purpose of disseminating information to practitioners in the fire field.

Fundamentals of Combustion Processes—Ease of ignition and the rate of flame spread across the surface of a polymer are related to its potential fire hazard. These polymer flammability characteristics depend on the chemical nature of the polymer, its surface condition, the form and orientation of the sample, and the environment in which it is placed. The NSF-RANN program at present supports six projects to develop suitable

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A. Phillips, and O. Cope, "Burn Therapy II: The Revelation of Respiratory Tract Damage As a Principal Killer of the Burned Patient," *Annals of Surgery*, Vol. *90*, 1982, p. 812.

H. Stone, and J. D. Martin, "Pulmonary Injury Associated With Thermal Burns," *Surgery, Gynecology, and Obstetrics*, *129*, 1969, p. 1242.

A. Zikria, W. A. Sturner, N. K. Ostarjeon, C. L. Fox, and J. M. Ferrer, "Respiratory Tract Damage in Burns: *Pathophysiology and Therapy Annals, New York Academy of Science*, *150*, 1968, p. 618.

understanding of these parameters so as to permit prediction of the behavior of materials in the presence of fire. As indicated in Table V, four projects are studying the mechanism of flame spread over solid surfaces and two over liquid surfaces.

Table V

Studies Pertaining to Mechanism of Flame Spread

Flame Spread over Solid Surfaces

Institution	*Research Area*
Brown University	Flame Spread over Solid Surfaces
University of California, San Diego	Fire Properties Along Solid Surfaces
University of Maine	Fire Rate of Spread in Paper Arrays
University of Utah (Chemical Engineering)	Flame Spread at a Solid-Fuel Oxidant Interface

Flame Spread over Liquid Surfaces

Institution	*Research Area*
Cornell University	Flame Spread over Liquid Fuels
Princeton University	Flame Spreading Across Liquid Fuels

The study of flame spread over liquid fuels is designed to determine the conditions that allow a fire to spread over a liquid surface maintained at sub-flash temperatures. Such information will be used to develop safe methods of storage and handling of flammable materials.

Three general pathways are available to the plastics industry to meet the present and future demands for reduced flammability characteristics of polymeric materials: (1) modification of chemical structure; (2) incorporation of inert extenders; and (3) the incorporation of fire retardants.

The design of flame resistance into plastics is essentially based on empirically gained knowledge. Due to economic considerations and technological limitations, the incorporation of fire retardants into existing materials in the form of halogenated organo-phosphates has been the most widely utilized method of meeting the flammability requirements. This should not limit future developments of the other two methods. Three NSF-RANN projects have programs dealing with the incorporation of fire retardants to enhance flammability characteristics and are listed in Table VI.

Table VI

Mechanism of Flame Inhibition and Fire Retardation

Institution	*Research Areas*
The Johns Hopkins University (Applied Physics Laboratory)	Chemical Inhibitions of Flames
The University of Utah (Flammability Research Center)	Effect of Fire Retardants on Smoke
SUNY—Binghamton	Extinction of Flames By Metal Powders

The University of Utah's program has as one of its objectives the determination of the effect of chemical retardants on the overall toxicity profile of the combustion products. We ask: does the addition of a fire-retardant chemical decrease the flammability but increase the toxicity of the combustion products?

A series of model urethane cellular plastics were prepared in the laboratory. They are representative of systems used in commerce. Table VII summarizes the fire retardants used in this study and presents the results of chemical analysis of these compounds. Table VIII summarizes the foam formulations used in this study.

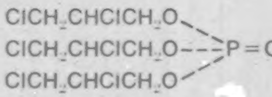
Thermochemical studies were conducted using a Mettler Thermoanalyzer to determine the principal parameters governing thermal degradation and combustion processes. Figure 9 illustrates the effect of heating rate (in air) on sample weight loss for the polymeric system fire-retarded with 8 per cent of the rigid urethane foam tris 2,3 dibromopropyl phosphate. Figure 10 illustrates the effect of heating rate on the thermal characteristics of the resulting exothermic degradation. The effects of environmental parameters on the combustion process are also being investigated.

The propensity of certain materials to ignite and burn with a rapid propagation rate has encouraged the industry producing these materials, as well as government agencies, to find ways of preventing or diminishing the ignition and flame-spread characteristics of these materials. The incorporation of flame retardants, while reducing ignition and flame propagation characteristics, may increase the smoking tendency of materials.

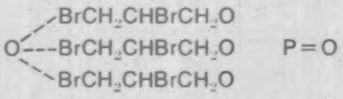
Several of the RANN programs are directed toward determining those factors, both physical and chemical, which govern the mechanism of smoke production of polymeric materials. These tasks will try to determine those parameters which cause emission of smoke particulates and

Table VII

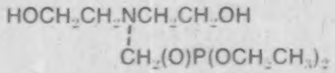
Fire Retardants and Analyses



Tris 2,3 dichloropropyl phosphate



Tris 2,3 dibromopropyl phosphate



o,o-diethyl-N,N′-bis (2 hydroxyethyl) aminophosphonate

	Tris 2,3 dichloropropyl phosphate	Tris 2,3 dibromopropyl phosphate	o,o-diethyl-N,N′-bis (2 hydroxyethyl) aminophosphonate
Formula Weight	431.95	697.69	255.26
Chlorine Content (%)	49.4	—	—
Bromine Content (%)	—	68.73	—
Phosphorus Content (%)	7.15	4.44	12.14

Table VIII

Rigid-Urethane Foam Formulations

	Foam 1 (pbw)	Foam 2 (pbw)	Foam 3 (pbw)	Foam 4 (pbw)	Foam 5 (pbw)	Foam 6 (pbw)	Foam 7 (pbw)	Foam 8 (pbw)	Foam 9 (pbw)	Foam 10 (pbw)	Foam 11 (pbw)	Foam 12 (pbw)	Foam 13 (pbw
Polymethylene polyphenyl isocyanate	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Propoxylated adduct—trimethyiol propane (M.W. 425)	100.0	89.8	79.6	70.6	57.3	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Silicone surfactant	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Tirchlorofluoromethane	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0
Triethylene diamine	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
o,o-diethyl-N,N′-bis (2 hyroxyethyl) aminophosphonate	—	9.3	18.6	26.8	38.0	—	—	—	—	—	—	—	—
Tris 2,3 dichloropropyl phosphate	—	—	—	—	—	9.8	20.4	30.9	44.5	—	—	—	—
Tris 2,3 dibromopropyl phosphate	—	—	—	—	—	—	—	—	—	9.8	20.4	30.9	44.5
Weight % fire retardant	0.0	4.0	8.0	12.0	16.0	4.0	8.0	12.0	16.0	4.0	8.0	12.0	16.0
% Chlorine	0.0	0.0	0.0	0.0	0.0	1.98	3.96	5.94	7.92	0.0	0.0	0.0	0.0
% Bromine	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.75	5.50	8.25	11.00
% Phosphorus	0.0	0.48	0.96	1.44	1.92	0.286	0.572	0.868	1.154	0.178	0.356	0.534	0.712

Figure 9

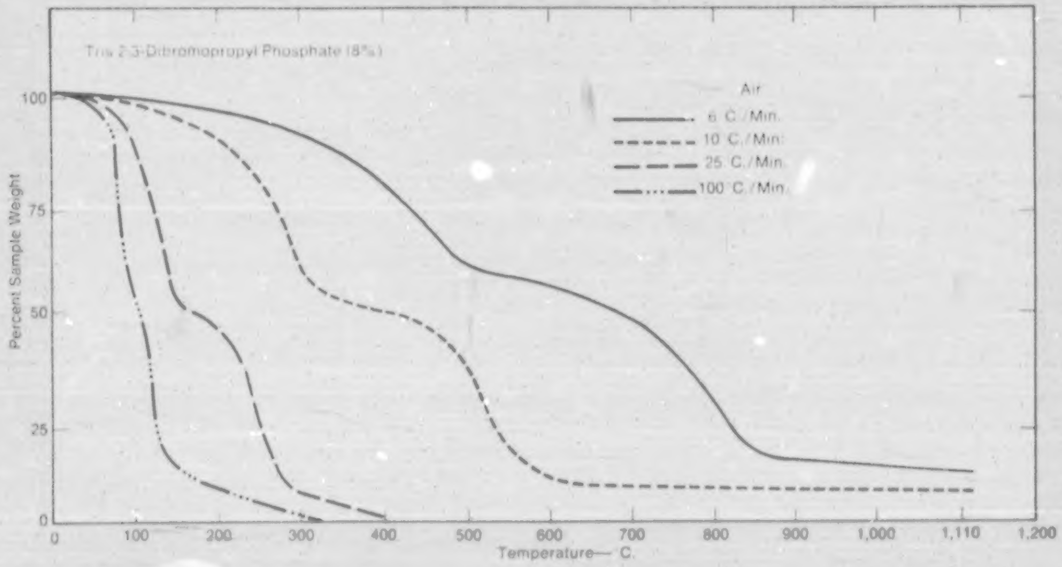
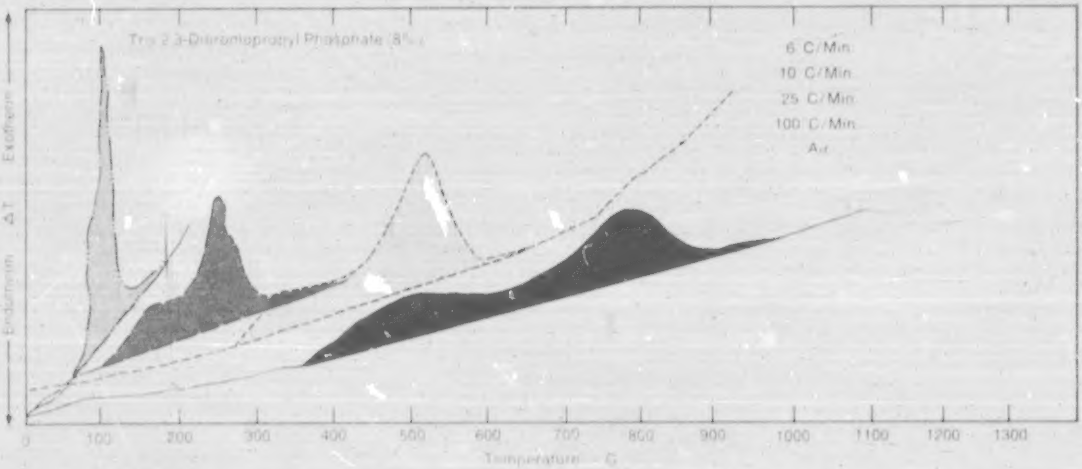


Figure 10



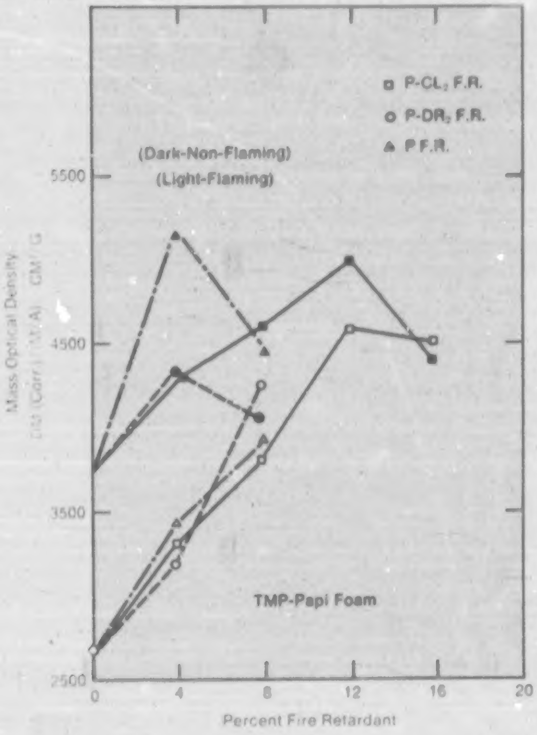
aerosols during pyrolysis or actual fire exposure. A study of the effect of fire-retardant structure and concentration on smoke emission in urethane polymers has been undertaken. Figure 11 illustrates the relationships existing between fire retardant structure and concentration and the smoking tendency of rigid-urethane foams.

The effects of heat flux, environment, polymer structure, and surface characteristics on smoke generation are also being studied.

Scaling and Modeling of Fires—Another NSF-RANN-sponsored project is being operated jointly by Harvard University and the Factory Mutual Research Corporation. Its primary objectives are to develop basic physical and chemical mechanisms that will permit modeling and scaling of large-scale fires.

A large-scale test facility, a bedroom, has been selected for comparison purposes. This room will be equipped as an ordinary room and the furniture ignited. A correlation will be developed to see if the test may be accurately used to model a "real-life fire."

Figure 11



Factors Affecting Survival During Fire Exposure—A series of experiments was conducted by members of the University of Utah's Flammability Research Center to determine the physiological effects on laboratory animals of carbon monoxide in smoke developed during the combustion of polymeric materials.

A maximum body temperature of 42° Centigrade (107.6° Fahrenheit) has been established as the ceiling temperature for Sprague-Dawley rats. Exposure at this level will produce major dysfunction in the central nervous system, the respiratory system, and possibly other systems and organs.

Utilizing an animal behavior conditioning chamber and an animal exposure chamber, it has been possible to classify the degree of carbon monoxide intoxication into five levels, as follows:

Level 1—Ataxic Behavior.

Level 2—Loss of Survival Response.

Level 3—Motor Collapse or Loss of Postural Tonus.

Level 4—Anoxic Shock.

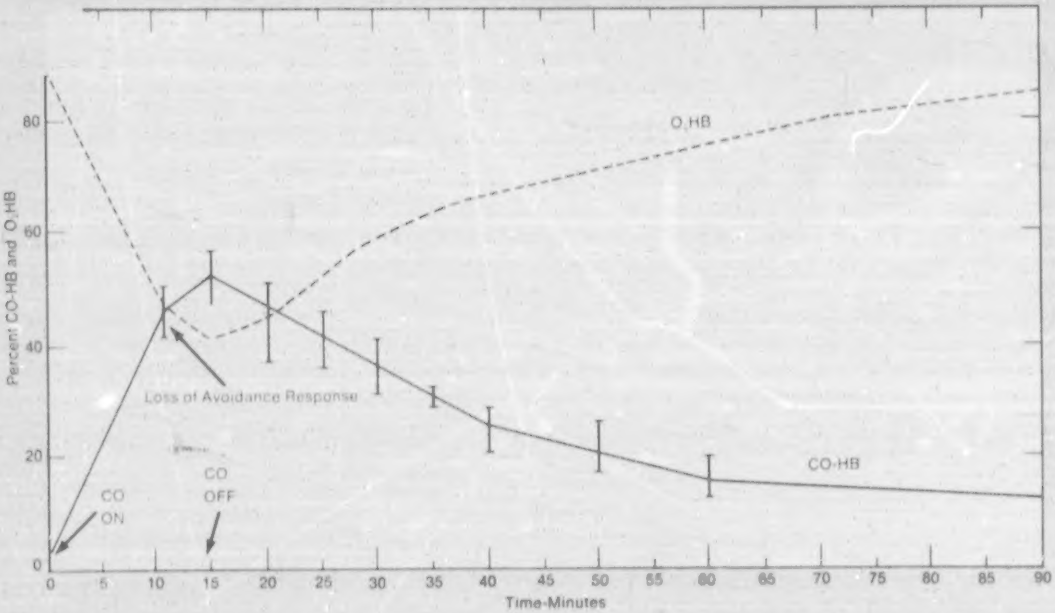
Level 5—Death.

A system was developed for removal of small quantities of arterial or venous blood during animal exposure via a heparinized cannula attached to a pedestal on the animal's cranium. During exposure chamber experiments, it is now possible to withdraw blood samples for a variety of determinations, including carboxyhemoglobin, oxyhemoglobin, electrolytes, serum enzymes, and various intoxicants.

Using small aliquots of blood (approximately 200 microliters) and the Co-oximeter, there has been developed an analytical technique that permits extremely rapid and accurate determination of oxyhemoglobin and carboxyhemoglobin. Figure 12 is a typical carboxyhemoglobin loading and unloading curve obtained on an experimental animal under dynamic exposure conditions. Loss of the animal's survival response occurred at 47 per cent carboxyhemoglobin; motor collapse was observed at a 65 per cent carboxyhemoglobin level.

By the use of the conditioning chamber, it has been possible to develop an animal model to measure the point of loss of survival response rather than the irreversible point of death. This model has also made it possible to observe the loss in learning ability as a response to exposure to moderate levels of carbon monoxide.

Figure 12



Also developed was a convenient method for the simultaneous determination of such vital functions as respiratory rate, EEG, EKG, peripheral nerve conduction velocity, reflex response latency, carboxyhemoglobin, oxyhemoglobin, serum enzymes, body temperature, and operant behavior. This system provides the capability for the determination of the effects of a variety of noxious gases and a number of factors affecting animal response, such as age, drug action, altered body temperature, and repeated chronic or acute exposure.

Pathologic Changes Resulting from Carbon Monoxide Exposure

Initial electron microscopy studies of the myelinated fiber of peripheral nerves of laboratory animals exposed to high concentrations of carbon monoxide show damage to the node of Ranvier, the area where saltatory conduction takes place (Figure 13). Associated changes in the Schwann cells with dilitation of the cisterns of the rough endoplasmic reticulum are shown in Figure 14. Occasional unmyelinated fibers show distortion and disintegration of internal structure, Figure 15. This damage can be seen at seven days after exposure to carbon monoxide with repair beginning as early as 14 days after exposure. These changes probably account for the temporary decrease in nerve conduction velocity.

Analysis of Fire Injury—NSF-RANN programs at both the University of Utah and the Applied Physics Laboratory of The Johns Hopkins University are studying human injuries caused by exposure to fire conditions. These programs have three principal objectives:

1. Determination of injuries caused by smoke: both short-range and extended illness leading to death.
2. Evaluation of the etiology of death by smoke or smoke constituents as evidenced by post-mortem examination.
3. Analysis of materials involved in fire.

Personnel of the University of Utah's Flammability Research Center have established a detailed investigative program in cooperation with the state and local fire services. The project

Figure 13

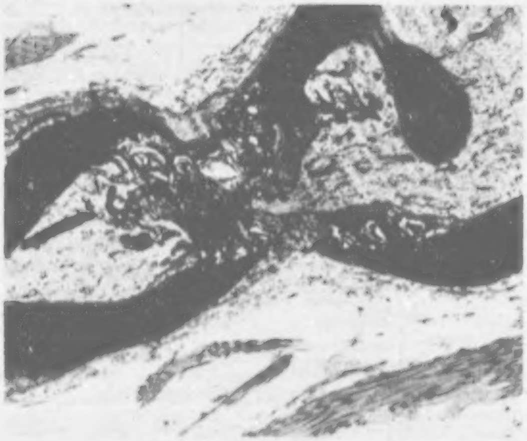


Figure 14

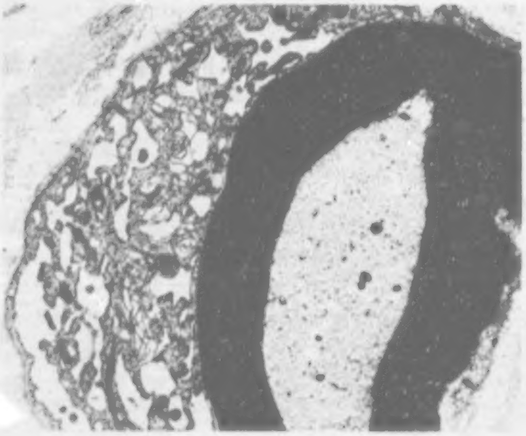
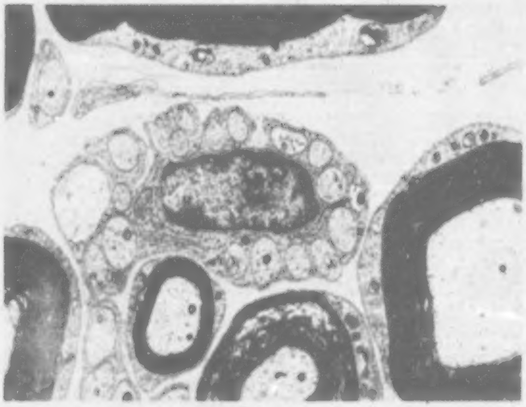


Figure 15



manager has been deputized as a Deputy State Fire Marshal and as a Special Consultant to the Salt Lake City Fire Department. Two vehicles have been equipped with two-way radio communications with the state and city fire services. One phase of these programs is a reconstruction of fire events as they occur.

Upon notification of a potential fire injury, project investigators proceed to the fire scene and, where possible, enter the burning structure to collect gas samples and record the fire progress with infrared photograph techniques. In the event of death, an autopsy is performed by the Medical Examiner of the State of Utah. Blood chemical analysis is carried out in conjunction with the project toxicologists.

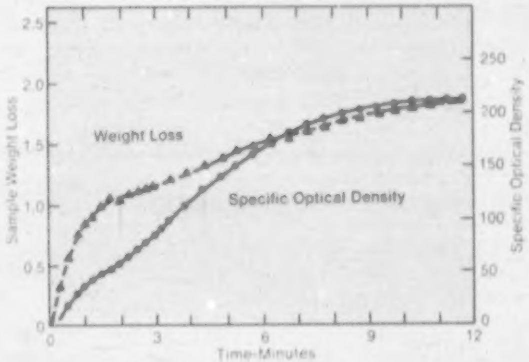
After the fire is brought under control, selected samples are returned to the laboratory for chemical and thermochemical analysis. Sophisticated analytical techniques are being developed to permit the development of a temperature profile which may have occurred during the fire. Analysis of gas samples is providing insight into the cause of inhalation injuries and the role materials, such as plastics, play in fire casualties. Typical case histories developed at the fire scene by project investigators in cooperation with the fire services are available on request from the Flammability Research Center, University of Utah.

Fire Loss Reduction Through Improved Standards—Fire and building code officials throughout the country have become alarmed by the increasing number of conflagrations involving plastics. Many laboratory-scale test procedures have been promulgated during recent years to evaluate the flammability characteristics of materials. Often no direct correlation exists between these tests and service performance.

Many of the NSF-RANN programs are designed to provide the fundamental understanding of fire, which may be used by standards and regulatory organizations in the development of more realistic criteria for materials' specification. A typical example of this effort is the development of relevant information pertaining to smoke development and light obscuration of materials during fire exposure by several NSF-RANN programs. In addition to this effort, the University of Utah's researchers are providing required physiological and toxicological data necessary for the promulgation of a hazard classification.

The Aminco-NBS Smoke Density Chamber was modified in order to house a force transducer and weighing platform for determining sample weight continuously during the combustion process. During smoke tests, sample weight and light transmission were logged by digital recorders every three seconds. The values of uncorrected specific optical density and sample weight loss for urethane foam as a function of time are plotted in Figure 16.

Figure 16



The newly-developed concept of mass-optical density, $D_s/(m/A)$ represents a more fundamental smoke index than specific optical density alone. It is not directly dependent on polymer thickness or density. Furthermore, it is independent of the surface area of the smoking polymer since

$$\frac{D}{\left(\frac{m}{A}\right)} = \frac{D\left(\frac{V}{AL}\right)}{\left(\frac{m}{A}\right)} = \frac{DV}{mL}$$

where:

D = specific optical density,

m = mass of particulates,

A = exposed material surface area, 0.0456 sq. ft.

V = chamber volume, 18 cu. ft.

L = light path, 3 ft.

This is another advantage because the active surface area is uncertain in many smoke tests. This new index is best utilized to compare various materials. This index determines the value of the maximum smoke optical density on a consumed-mass-normalized basis. Figure 17 is a plot of the mass-optical density as a function of time for eight materials under non-flaming conditions.

Preliminary experiments have been conducted by placing animals within the smoke chamber in an attempt to develop a correlation of survival response with the previously described mass-optical density. A smoke density-physiological response plot is illustrated in Figure 18. The products of combustion are being determined through use of a computerized analytical system. When this technique is refined, it should provide the basis for a first evaluation of the potential toxic products hazard.

Systems Approach to the Fire Problem—The NSF-RANN programs are developing an improved research base and new technology which will be used in the employment of a systems approach to facilitate the reduction of fire losses. Table IX summarizes the components utilized in this system.

Figure 17

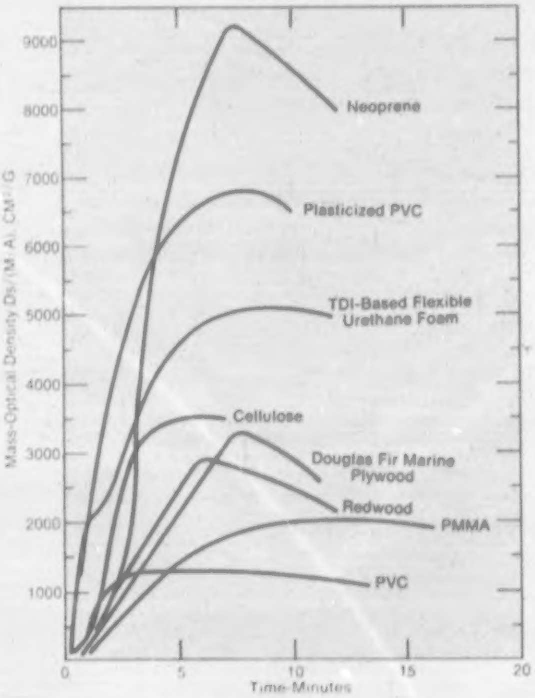


Figure 18

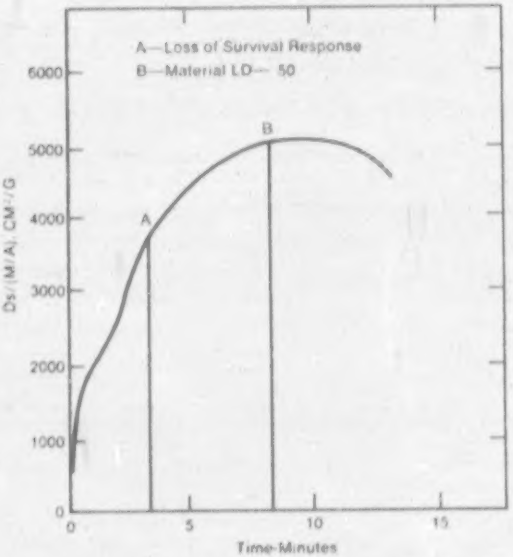


Table IX

Systems Approach to Fire Loss Reduction

Fundamentals of Combustion.
Educational Programs.
Architectural Design Considerations.
Early Detection Systems.
Fire Suppression Systems.
Life Support Systems.

An educational program must be developed to provide pertinent information to code officials, architects, structural engineers, and fire service officials to insure engineering design for maximum fire safety. This systems approach will involve the use of early warning detection and reliable fire suppression systems. Special consideration will be focused on the unique problems encountered in high-rise structures to provide safe areas for life support.

Ancillary Benefits Provided by NSF-RANN Fire Programs

As a result of the fire research programs a number of ancillary benefits have been realized. These include, but are not limited to, the following:

1. A method of cleaning oil spills by combustion techniques.
2. Development of computerized chemical analytical techniques for arson investigation.
3. Techniques for determination of leakage from fuel storage sites.

Summary

The NSF Fire Research Program covers the spectrum from basic to applied research and is directed at critical elements of the nation's fire problems. Through close coordination with other Federal agencies, there has resulted a research effort that is complementary and often permits study on longer-term payoff areas than is usually possible in a mission agency. Projects contain utilization plans, coupling with potential users, and periodic progress reviews to accelerate the transfer of research results to useful purposes and to provide the research people with a knowledge of needs of practitioners.

The NSF-RANN program has demonstrated the progress that can be realized through a well-coordinated continuing national fire research effort. This type of effort will prevent the need to legislate programs based on fire disaster.

ENVIRONMENTAL THREATS TO MAN

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How much could changed research alter the nation's response to earthquakes, floods, frosts, hurricanes and other natural hazards? At the University of Colorado, a group is addressing this question. The group includes economists, engineers, geographers, a lawyer, meteorologists, psychologists and sociologists. It works with experts of the National Center for Atmospheric Research, Travelers Insurance Company and Colorado State University, and representatives from the Federal Departments of Agriculture, Commerce, Defense, Housing and Urban Development, and the Interior, and selected state and municipal agencies across the country.

We are trying to ask this question in a way useful to researchers and administrators in agencies that allocate research funds and apply research results.

The aim of this projec[illegible]Assessment of Research on Natural Hazards—[illegible] to take advantage of the theoretical frameworks and detailed studies already developed for limited sectors of the problem. This will make it possible to analyze the national situation with regard to major geophysical hazards, and in collaboration with the concerned public agencies to develop a statement of the immediate policy alternatives and a recommended program of research to meet the more urgent needs. The project is supported by a grant from the NSF-RANN Program.

The first step has been an assessment of two things: the present and prospective losses from natural hazards, and the alternative, feasible ways of reducing their unfavorable economic and social aspects. This assessment results in an appraisal of the likely social gains and costs of adopting each of the present and practicable new alternative policies for dealing with natural hazards. Based on the results of the assessment, the second major step is to prepare a statement outlining the specific character and magnitude of needed research efforts and their expected short and long-term payoffs.

As a minimum, the effort provides a basis for evaluating fundamental public policy alternatives and new research programs relating to geophysical hazards. It is expected to offer specific suggestions for state and Federal planning-related research activity. It might or might not result in innovative policies and research proposals.

The effort canvasses several lines of activity that have advanced far in coping with one hazard, but not with others. For example, the estimate of payoff from research on earthquake-resistant structures is extended to flood-resistant structures. How many of the appraisal results will be translated into revised policy, procedure, or budget cannot be predicted. But the entire assessment is conducted so as to enhance the likelihood that concerned Federal and state agencies would be disposed to act upon the findings.

The assessment focuses on the following geophysical hazards:

Avalanche
Coastal Erosion
Drought
Earthquake
Flood
Frost
Hail
Hurricane
Landslide
Lightning-Caused Forest and Range Fire
Tornado
Tsunami
Urban Snow & Ice
Volcano
Wind

The basic questions for initial consideration by the project staff are listed below. For each hazard we have tried to answer the following questions:

1. What data are available on losses due to the hazard?
   —Direct losses.

- —Secondary or indirect losses including long-term hard-to document losses.
- —Geographic distribution of such losses: national, regional, state and local levels.

2. What is known about the quality of these data—comprehensiveness, validity, etc.? This includes the problems of comparability of data collection and aggregation across the various types of hazards.

3. What is known of the effectiveness of current mechanisms used to cope with each hazard? This includes efforts at prevention or mitigation of the hazard, detection, warning and evacuation, land use controls, requirements for construction and maintenance of structures, compensation including insurance, pre-disaster planning for post-impact response, post-impact relief efforts, reconstruction and rehabilitation.

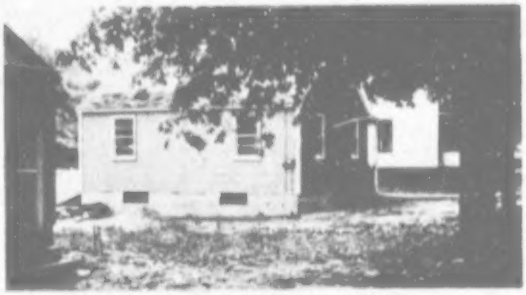
4. What is known of the probable effectiveness of alternative mechanisms that might be used for coping with each hazard? This includes the status of research and demonstration efforts on the various alternative coping mechanisms.

5. What is known about the costs and payoffs (including unanticipated negative consequences) of each of the currently used and potential alternative coping mechanisms?

To start with a simple example:

On the Housatonic floodplain in New England is a house that was partly washed off its foundations a year ago (Figure 1). Its owner is rebuilding. A neighbor about to build a new house sees himself as taking no risk. The former is willing to invest in new Federal Flood Insurance; his neighbor is not and resents any effort to regulate new building in the hazard zone. Why? The former expects to sell the house within six months. The latter feels assured that he will not suffer another flood because he mistakenly interpreted what hydrologists told him to mean that 100 years would pass before a flood of that magnitude would occur again.

Figure 1



What Is Happening?

From analysis of the results of a whole series of individual and collective decisions, we begin to judge the extent to which additional scientific and technical knowledge has been or might be used in coping with natural hazards. Examination of the factors contributing to those decisions illuminates the points at which changes might take place.

Take the record of floods. Correcting for both population and prices, we can trace over a period of seventy years the course of per capita national property damages and deaths, and identify trends in them (Figure 2). This raises questions as to why particular combinations of action have been adopted and whether new information would influence the cause of events.

Similarly, we can examine in Table I the trends for each of the whole range of hazards with which we are dealing.

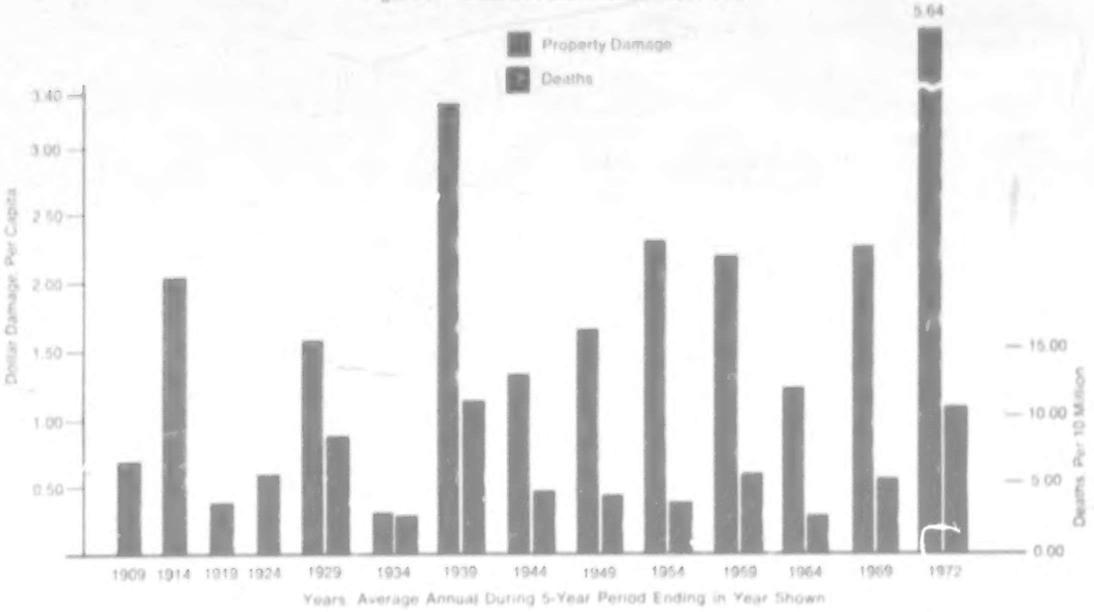
We thus arrive at tentative judgments as to certain aspects of what is happening. For some hazards, property losses are going up, loss of life is going down (but not in the case of earthquakes), and there is developing a greater vulnerability to large, infrequent catastrophic events.

However, there is virtually no information available on other important aspects of hazard experience. It would be desirable to know the full range of cost and benefits of all adjustments which are made to the extreme event. Take societal response to hail, for example. The possible adjustments include the mechanical efforts to suppress it by cloud seeding; the issuing of warnings; research to develop non-vulnerable crops; changes in the pattern of those crops so as to spread the risk; and crop and property insurance. We need to know the total social costs of these adjustments and to estimate the balance

Table I: **Preliminary Estimates of Losses, Deaths and Potential for Catastrophe**

	LOSSES		DEATHS			
	Average Annual $ Million (10 Yr. Base)	Trend	Average Annual (10 Yr. Base)	Trend	Catastrophe Potential	Present Level of Adjustment Expenditures $ Million
Avalanche	1	Upward	7	?	Low	?
Coastal Erosion	300	Upward	0	Level	Low	?
Drought	500	?	N. A.	N. A.	Medium	?
Earthquake	100	Upward	9	Upward	High	?
Flood	2,000	Upward	129	Downward	High	?
Frost	1,000	Upward	0	Level	Low	?
Hail	550	Upward	0	Level	Low	?
Hurricane	400	Upward	50	Downward	High	?
Landslide	200	Upward	?	Level	Low	?
Lightning	50	?	115	Downward	Low	?
Tornado	215	Upward	101	Downward	High	?
Tsunami	10	N. A.	12	N. A.	High	0.5
Urban Snow	20	Upward	?	Level	Low	?
Volcano	N. A.	N. A.	N. A.	N. A.	High	0
Wind	100	Upward	50	Downward	Medium	?
Totals	5,446	—	473	—	—	—

Figure 2—**Losses in U.S. Floods 1905-1972**

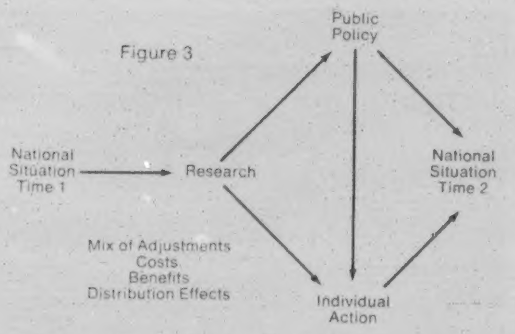


between the costs of losses in property and lives and the costs of adjustments, as well as the benefits that come from occupying and developing hazardous areas.

Could Research Foster Improvement?

The assessment of a particular hazard begins with a statement at Time 1, say 1970, about the current mix of adjustments for the nation, of the costs and benefits, and the effects on various sectors of the population (Figure 3). Then it asks: what kind of research might have a significant effect on individual action—directly, or through public policy decisions—in Time 2? The analysis then proceeds to investigate what interactions might account for a change from one time to another, if indeed any change occurs. The result is to determine the social utility of various kinds of research and, in the process, to stimulate a continuing analysis on the part of the agencies concerned.

Figure 3

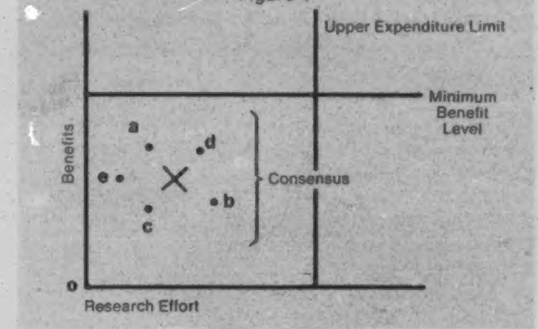


Methods and Tools

We have used a number of devices to do this. The decision process for allocating funds to natural hazards research has been haphazard at best. While detailed expenditure programs usually are appraised with minute care at budget and legislative levels, only the most gross estimates of potential benefits are developed and cost estimates often appear to materialize out of thin air. To continue this almost casual acceptance of implied research priorities is to invite over-expenditures in some directions and under-expenditures in others.

Indicative of one common type of analysis utilized in establishing appropriate funding levels for natural hazards research, is the report by the Committee on Public Engineering Policy.[1] Essentially, that report utilizes an informed *consensus* method by which priorities and research expenditures are agreed upon. Competent and experienced people are asked to share their judgments. Figure 4 illustrates the process whereby members of a committee each indicate their relative preferences (points A, B, C, D, etc.); the final decision is the mean of these (point X), with the mean often being affected by the weight of influence exercised by each member.

Figure 4



It is a rare scientific discipline or policy field that has not been the subject of an evaluation of research needs at one or more times over the past two decades. These always require assumptions as to public aims, although the aims may not be specified. Research reviews of this type range from the hurried to the deliberate, and reflect the composition and interaction of the groups taking part. They may lay heavy stress on advancing a discipline, helping a particular user group, or defining new problems. In stance, they may be self-serving political compromises, or highly objective.

The appropriation and authorization process concerning research payoffs and opportunities—in Congress, and to a lesser extent in state legislatures—is a significant part of the research or program evaluation process. Agency review of research opportunities may include social methods or ways of judging research payoffs or opportunities: cost-benefit analysis, cost effectiveness or a consensus of experts as to the type of research that should be afforded budgetary and authorization priorities. The National Science Foundation uses both group and individual (18,000 in a year) evaluation of research priorities during its consideration of 14,000 research proposals in a year. Other research funding organizations follow somewhat similar methods of peer review. In turn, such groups or individuals in a summary judgment utilize cost-benefit and other methods, sometimes made explicit and sometimes implicit. At one time [illegible] Department of Agriculture sent out a questionnaire to all the land grant colleges and ag[illegible]ural schools asking what their research prior[illegible]ere. However, the process is now more sophisticated.

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[1] Committee on Public Engineering Policy, National Academy of Engineering, *Priorities for Research Applied to National Needs*, Washington, D. C., 1973, RANN Document No. NSF/RA/X-73-014.

Another common mode of analysis is also represented in Figure 4. The cost-effectiveness approach either puts an upper limit on expenditures, or determines a minimum level of benefits to be achieved at the lowest practicable cost. It begins with an agreed objective and examines the likely benefits of different actions. The cost-effectiveness approach in government appears at times in the discussions between the Office of Management and Budget (OMB) and an individual agency as to how the agency program and budget fit into the final budget of the United States. The President determines an upper limit to the Federal budget; OMB officials are then responsible for recommending upper limits among agencies to stay within the President's budget priorities.

We use a variety of tools. They include the following:

A literature review.

Estimates of benefits from possible adjustments.

Estimates of costs.

Simulation models of the relationships that seem to account for the occupation of various hazard areas.

A scenario analysis of what has happened and what might be expected to happen in particular situations with different inputs of science and technology.

Workshops with reviewers and consultants.

Finally, the production of a list of research opportunities evaluated by a set of criteria that have been carefully sifted out over a period of a year.

The assessment is begun for each major geophysical hazard with a *literature review* aimed at assembling past judgments as to needs. These are supplemented by analyses of current losses, benefits, adoption of adjustments, and research activities. In the summaries distributed for conference review no references are cited, but full sets of references accompany the longer draft reports.

In instances where data and time permit, estimates are made of the cost effectiveness of possible adjustments to individual hazards, as in calculating the cheapest way of attaining an agreed goal.

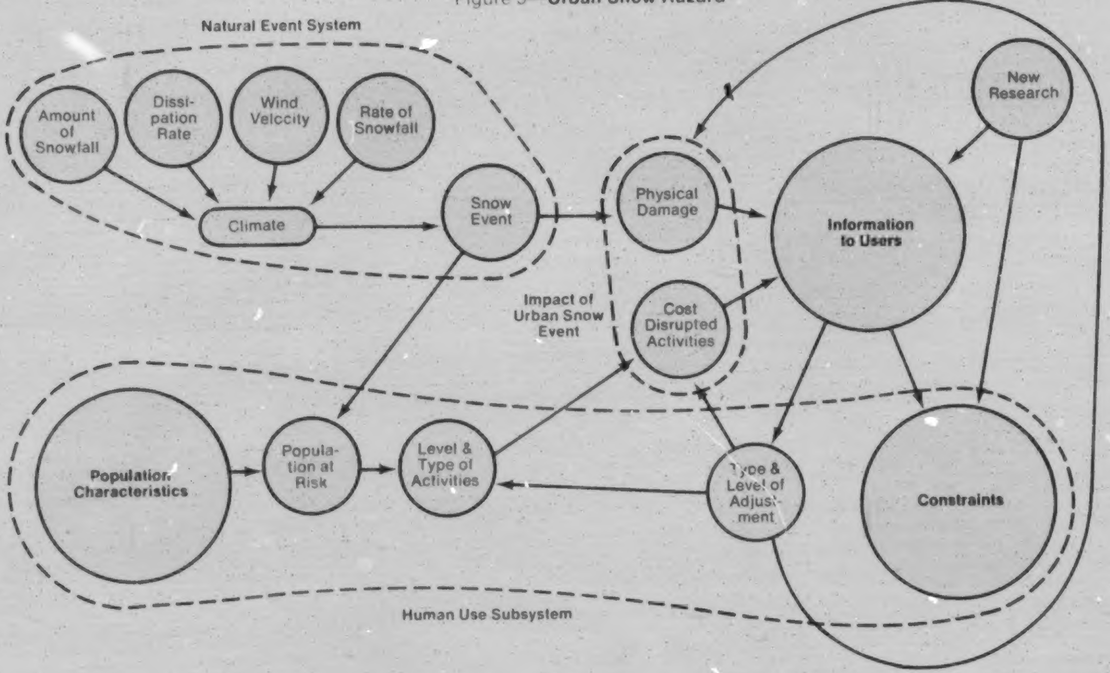
Within the same limits, estimates are made of the *costs and benefits* of possible adjustments as a means of calculating the order of magnitude of the likely net benefits from a postulated change in adjustment. It often is easier to calculate benefits than total social costs.

Estimates of social effects of changing adjustments may be facilitated in a few instances by simulation modeling and by scenario analysis. The two are closely related.

If we were to understand fully the ways in which one adjustment—such as insurance—affects another adjustment—such as land use planning—we could predict with some confidence the effect over time of changing the policy on insurance premiums. We would thereby gain insight into the land-use consequences of research designed to find ways of increasing the voluntary purchase of insurance. By attempting to simulate those interactions we would test the adequacy of present knowledge. To the extent that the evidence permits, we would be able to estimate the prospective results of changing one of the variables. Thus, a rough attempt can be made to model the relationship between an increased flow of information to municipal officials and the physical damage and disruption cost of heavy rapid snow fall in urban areas, as indicated in Figure 5.

Simulation also can be used to estimate the consequences of the occurrence of a physical event in a different place or time. The work of Don G. Friedman at Travelers Insurance Company provides us a basis for calculating the earthquake intensity for a section of the nation, such as Southern California, if an earthquake of a given magnitude, depth and epicenter location were to occur. Figure 6 illustrates the geographic variation within California and adjacent states. The areas on the map are uniform in the impact of a hypothetical earthquake.

Figure 5—**Urban Snow Hazard**


Natural Event System
Amount of Snowfall
Dissi-pation Rate
Wind Velocity
Rate of Snowfall
Climate
Snow Event
Physical Damage
Impact of Urban Snow Event
Cost Disrupted Activities
New Research
Information to Users
Population Characteristics
Popula-tion at Risk
Level & Type of Activities
Type & Level of Adjust-ment
Constraints
Human Use Subsystem

By constructing scenarios of what would have happened in particular hazard areas with specified combinations of adjustments at given times it is possible to test some of the ideas growing out of the simulation modeling and to identify critical types of information inputs and policy decisions. Thus, the potential property damage from floods in Rapid City, South Dakota can be estimated for 1955-1980 with different assumptions as to growth rate and adjustments adopted (Figure 7).

The long-term effects of no additional adjustments, a regulatory program, a protection program, and a warning program then can be compared.

Major Issues

Scenario analysis and explanation of adoption of adjustments leads us into several sets of major issues. Review of the state of research on natural hazards suggests that the shape and weight of future work in these fields will be guided in large measure by the position taken by government agencies with respect to a few issues of public policy. One set of issues is a case in point. These relate to the practicability of incorporating natural hazards adjustments in national and state programs of land-use planning of the type that is now before the Congress.

What is the practicability of incorporating natural hazard adjustments in national, state, and local land-use planning? National support of land-use management is expanding in the present period and hazards are mentioned frequently as an important consideration in such planning. Yet little is known, for instance, as to the costs and direct benefits of using available hazard data in designating land uses in local regulations. There is question as to whether hazard considerations are to become a solid and integral part of nationally stimulated land-use planning. If so, the scanty experience and large opportunities in land-use management will need to be examined promptly, critically and imaginatively.

Figure 6

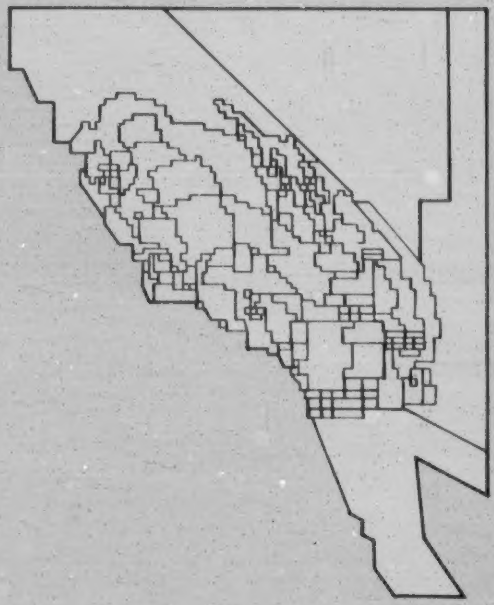
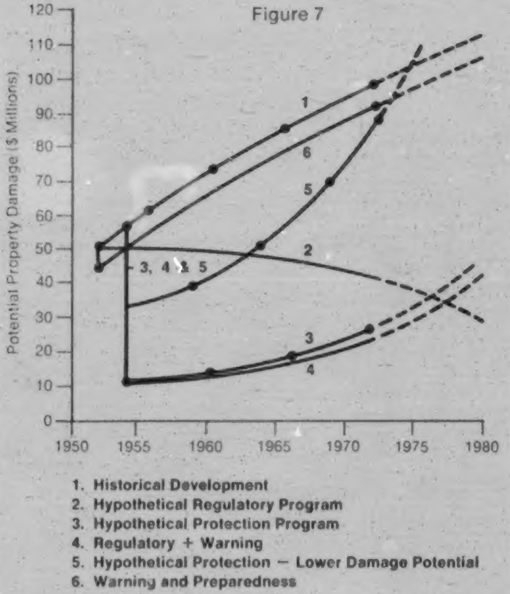


Figure 7



What is required to obtain reasonably accurate delimitation of hazard areas? Without moderately accurate and legally admissible delimitation of hazard areas, much insurance and most land-use management cannot proceed. There is doubt as to how rapidly the mapping of susceptible areas can be accomplished in a fashion that will satisfy legal criteria for regulation. If the nation is serious about emphasizing these approaches to hazards, a new and vigorous effort must be made to lay the groundwork for accelerated mapping programs.

There is a pleasing and sometimes very comforting kind of solution that many of us are inclined to favor: i.e., if we just undertook to plan adequately at the municipal and state level we would avert or largely mitigate the losses which the society will have in the future. To test this kind of conclusion, it is necessary to examine what, in fact, has happened with land-use planning efforts and what the technical and societal limitations are of applying new research findings. For example, we might look at a sample flood plain in which part of the city is outside the plain and part lies within it. If we do this, we can ask what would be the economic and social consequences over a period of time of shifting the land use in this area over into the more protected areas, of readjusting building structures and improving warning systems, and the like (Figure 8). The answer is not always as simple as it seems at first blush, and the complications involved in attaining an effective mix of these activities are great indeed. We must attempt to specify what kinds of public measures or research on such measures would assure the application of technology in these circumstances.

From land-use planning, we can move into several other sorts of problems that present themselves. We have very preliminary findings on these problems at this stage.

Types of Findings

For example, as a rough model of the way a hazard warning system operates, Figure 9 is instructive. Analysis of these relationships shows that in few if any instances is there at work in the United States a system that is complete. I mean complete in the sense that from forecast time to the final response there has been adequate recognition of the processes that are work, and assurance that when the forecast is issued, it indeed has the expected effects. Findings of this type lead to suggestions of change in emphasis in research on the part of the agencies responsible for sectors of the warning activity.

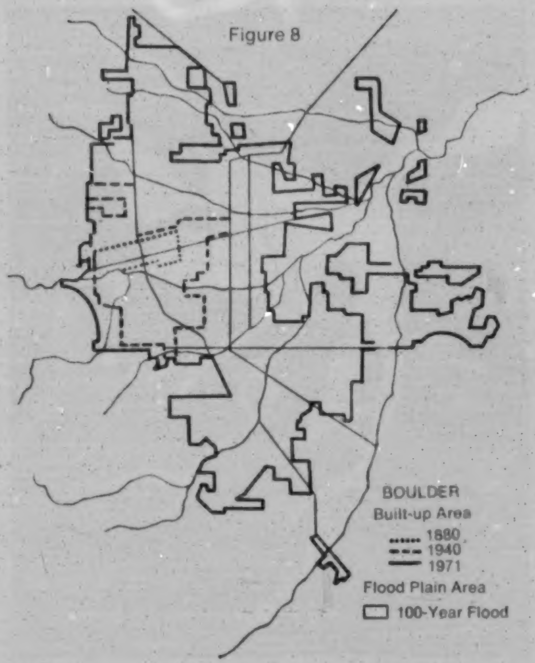
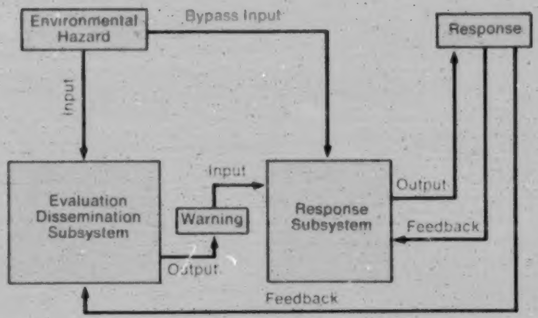


Figure 8

BOULDER
Built-up Area
1880
1940
1971
Flood Plain Area
100-Year Flood

Figure 9—**Model of a Warning System**


Environmental Hazard
Bypass Input
Response
Input
Evaluation Dissemination Subsystem
Input
Warning
Output
Response Subsystem
Output
Feedback
Feedback

A deceptively simplified fashion of presenting the results of the analysis is to evaluate the spectrum of possible research on a given hazard according to selected criteria. We are doing this but we recognize that the criteria may neglect consideration of matters that, while less readily quantified, may be more influential in the long run. The criteria applied to research opportunities at this stage include:

Benefit-cost ratio for the adjustments affected.

Measures of effect on human health.

Measures of social disruption.

Anticipated impacts on environmental quality.

Distribution of economic effects by income groups.

Expected practicability of adopting the research findings.

These are in course of revision and extension.

The early weeks of this investigation were vigorously punctuated by the Rapid City flood and tropical storm Agnes. We hope we will get through next Spring without having our findings underlined by another expression of concern on the part of Nature. But, regardless of that, two things seem likely from an appraisal of present conditions. One is that the prospects of very damaging responses to natural events in the United States are increasing. The other is that the nation is becoming more, rather than less, vulnerable to major systemic catastrophes. We hope that out of this assessment will come some judgment of where further research and development inputs would be most likely to avert catastrophe rather than to exacerbate it. We hope also that the assessment may stimulate in public agencies a keener appreciation of what the large payoffs are and how they might be captured.

Threats to the Natural Environment and Environmental Management

RANN APPROACH TO ENVIRONMENTAL RESEARCH

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Since its inception in 1971, RANN has given strong support to a program of environmental research. The goal is to provide the scientific basis for managing our environment at a time when Government and industry decision makers must have the best information and best understanding of the environmental consequences in the choices they are making.

The basis for the environmental research program is the realization that management usually cannot predict all of the results of its important decisions. Also, issues facing us today are intractable when approached on a fragmentary or disciplinary basis. Furthermore, problems of the environment are often regional in character, but decision structures meeting these problems tend to be localized.

The Division of Environmental Systems and Resources manages more than 200 active research projects, each reviewed by the scientific community and by representatives of users of potential project results. Suggestions and criticisms by the reviewers have often caused major adjustments in the research or management plan before funding has been approved. In addition to its scientific merit, each project is expected to have strong impact on policies and operations carried out in Government and private industry.

Program objectives are:

- **To define specific environmental problems, inventory policy and management alternatives in meeting the problems.**
- **To analyze the resources impacted and ecosystems affected.**
- **To analyze the economic and social consequences of management decisions affecting the environment.**
- **To synthesize and evaluate management strategies and practices for retaining environmental values.**

These objectives are intended to provide a strengthened research base between mission or operational agencies and the scientific community. Team approaches are followed in studying environmental problems. Short-term impacts on specific problems, and longer term inputs on major resource management problems, are both a part of the program's grant package.

It is not practicable to study all aspects of energy-environment relationships or interactions between materials and environment, but at the present time three major program elements are active. Each is highlighted by examples of selected investigators and data users in the papers that follow.

The three program elements are:

- **Studies on trace contaminants in the environment.**
- **Some aspects of weather modification.**
- **A broad category of studies covering regional environmental systems.**

The Trace Contaminants program is principally concerned with determining the levels of toxic substances in the environment, assessing the effects of those levels on plant and animal communities including humans, and relating these findings to methods of control. Most of the effort has been applied on lead, mercury, molybdenum, and the zinc-cadmium complex of metals. Other work has been done on nitrate in soils and water as a product of agricultural fertilization practices, and atmospheric particulates and gaseous pollutants. Improved techniques and instrumentation in analytical chemistry have also been developed, as will be noted in Dr. Frank Hersman's paper later in this volume.

The Weather Modification Program is developing an understanding of the mechanism of hail formation in severe storms to determine whether, when and how the formation of damaging hail can be suppressed. The ways in which large cities and industrial areas may produce anomalies in local weather patterns are also studied, so that effects of fog or heavy precipitation can be predicted and prepared for. RANN maintains close ties with the Interdepartmental Committee on Atmospheric Sciences, a Federal agency consortium that guarantees communication and coordination among government studies on the atmosphere. The impact of planned weather modification on social, economic, legal and ecological aspects of the area under treatment is also studied.

The Regional Environmental Systems program focuses on the issues of land use and management, giving particular attention to coastal zones and estuaries—highlighted in the Fruh and Mosely papers—semi-primitive areas and the urban-rural interface.

The planning and management of a region or a resource for maximum societal benefit and minimum environmental insult requires an ability to evaluate the consequences of all possible alternatives, an ability that the Regional Environmental Systems program seeks to enhance in governmental and industrial sectors.

MISSOURI LEAD BELT PROJECT

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DR. WIXSON:

Missouri as noted in the NSF film entitled "Lead—A Four Letter Worry" is the source of 80 per cent of the U.S. total lead production, which had a value of some $185 million in 1972. In just six years the Viburnum Trend, or "New Lead Belt," has become the largest lead-producing district in the world. It is 75 miles southwest of St. Louis, largely within the boundary of the Clark National Forest, see Figure 1.

In 1965, five new mines and two new lead smelters began actively planning and preparing for production, and environmental concern was part of the planning. All of the companies soon became acquainted with the people of the various Federal and state agencies as well as the University of Missouri-Rolla. During the next six years St. Joe Minerals Corp., American Metal Climax, Inc., Cominco American Incorporated: Ozark Lead Company (Kennecott) and American Smelting and Refining Company participated in research efforts and made properties, equipment, manpower, information and funding available for University of Missouri-Rolla scientists and engineers. The companies also actively engaged in information exchange meetings, development of needed analytical methods and use of research findings for the modification or construction of pollution abatement facilities.

One of the environmental problems, which initiated a more formalized cooperative research program, occurred in August 1970. Discoloration or bronzing was noticed in the new growth on the top of trees downwind from a smelter stack. Concern about this manifestation called into existence a cooperative research effort among the Amax Lead Company of Missouri, the University of Missouri, the U.S. Forest Service and other Federal and state agencies.

The Forest Service provided vegetative studies and sulfur dioxide and climatologic monitoring instruments. The U.S. Bureau of Mines and the U.S. Geological Survey provided background data and technical assistance. The Missouri Division of Geological Survey and Water Resources volunteered its expertise in aerial photography. The Missouri Air Conservation Commission provided data, sulfur dioxide equipment, and technical assistance. The Missouri Department of Conservation and the University of Missouri Environmental Trace Substances Center performed biopsies and analyses of the effects of emissions on the fauna of the area. Additional data collections and information relative to the study area were supplied by the U.S. Environmental Protection Agency and the Missouri Clean Water Commission.

Task Assignments

Correlating and interpreting the data collected by the various investigators were the tasks of the University of Missouri-Rolla research scientists, who also devised methods and equipment to allow the Clark National Forest and the "New Lead Belt" to coexist in peace and harmony. As a subsequent outgrowth of these efforts, the NSF-RANN Trace Contaminants Program funded the University of Missouri to provide additional lead study research along similar lines throughout the new lead belt area.

Sample grids were established around the smelter as well as continuous sulfur dioxide monitors, dustfall buckets and sulfate candles. An existing meteorological station was repaired and

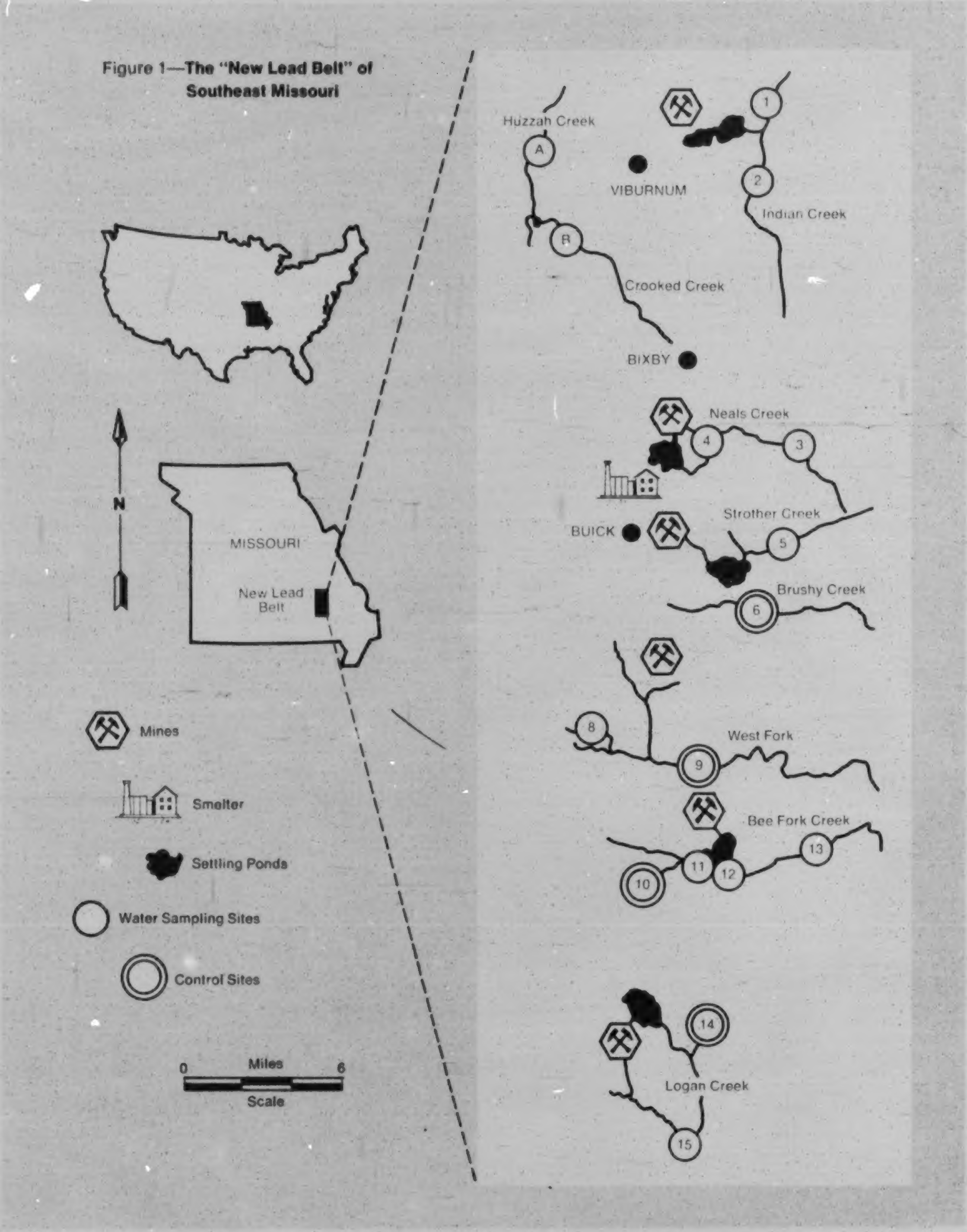


Figure 1—The "New Lead Belt" of Southeast Missouri

N
MISSOURI
New Lead Belt
Mines
Smelter
Settling Ponds
Water Sampling Sites
Control Sites
0
Miles
6
Scale
Huzzah Creek
A
1
VIBURNUM
2
Indian Creek
B
Crooked Creek
BIXBY
Neals Creek
4
3
Strother Creek
BUICK
5
Brushy Creek
6
8
West Fork
9
Bee Fork Creek
13
11
12
10
14
Logan Creek
15

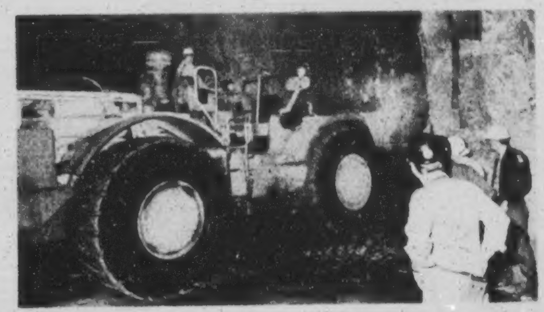
a second meteorological station was estabilshed at a nearby fire tower. Then a program of data collection, equipment servicing and analysis was set in motion.

In general, the university directed the program, set standards, provided much of the analysis and correlated and interpreted the data.

As a result of this research it has been established that excessive sulfur dioxide and acid mist emission from the smelter were the causes of premature tree browning in the late summer of 1970. It was further established that a higher than background pattern of sulfur and lead in soil and vegetation was noticeable immediately around the smelter. Recommendations for control actions in these problem areas were then passed on to the industry.

The typical mine-mill operation is composed of underground mining, as in Figure 2, and milling, where the limestone/mineral mix is processed into lead, zinc and copper concentrate for shipment to the smelter and the residual limestone is discarded as tailings. This residue, which also contains traces of minerals, is deposited in "tailings ponds" where the solids settle out and the excess mine and mill water is discharged.

Figure 2



This produces several sources of pollution. They include subterranean mine water, minor oil spills and incorporation of finely ground rock and minerals into water from the milling process, which also contains traces of organic flotation reagents. These mine/mill effluents have stimulated algae growths that coated stream beds causing aesthetic problems and disrupting normal stream populations. These biological mats act as living filters to extract dilute nutrients and to filter out finely ground particles of limestone, lead, zinc and copper, which escape the tailing ponds.

Through interaction with the industries and agencies concerned, experimental treatment procedures were recommended to solve this problem. In Figure 3, Mr. Anderson is shown discussing the new environmental controls with representatives of the U.S. Forest Service and University of Missouri researchers.

Moreover, virtually all of the participating Federal and state agencies are using scientific data collected by this study in the development of improved air and water standards and regulations. Further, as a result of a visit by the British Zuckerman Commission on Mining and the Environment, this project is being cited as a model program in terms of cooperative spirit and social relevance in solving a common problem.

Figure 3

MR. ANDERSON:

As soon as it became evident what the results of the study were, the company, the university, the U.S. Forest Service and other interested state and federal agencies sat down together. We set aside our potentially adversary positions and, instead, pushed facts and hypothesis into view reviewing them with a common goal—**to solve the problems.**

By holding several face-to-face exchanges among the environmental investigator, the regulator and the operator, we learned to recognize each other's problems. We learned not to oversimplify. We avoided costly false solutions. And, we solved a few problems.

Control Measures

The following are examples of some of the control measures that were implemented:

Concerning the sulfur dioxide problem at the Smelter:

1. The smelter recovers about 70 per cent of the sulfur dioxide in the form of sulfuric acid. Acid mist emission from the acid plant was identified as the most serious problem and was attributed to certain inadequacies in the plant itself. A "high efficiency" mist eliminator and additional cooling capacity were installed and the problem appears resolved. This has resulted in improved acid plant efficiency, increased acid production, improved sulfur recovery, and reduced sulfur dioxide emissions. It cost $360,000.
2. Four permanent ambient sulfur dioxide monitoring stations were installed. Results are telemetered to the smelter and, whenever the ambient level at any station exceeds the Missouri one hour standard (0.25 ppm) for 10 minutes, the sinter/acid plant is shut down. This installation cost $50,000.
3. A continuous stack analysing system is being installed. This will cost $20,000.
4. Studies are under way to replace the present 200-foot-tall stack with a taller one. This will *not* allow increased emissions, but will reduce ambient sulfur dioxide levels. Estimated cost: $1 million.

Concerning lead contamination immediately around the smelter:

1. Two dams were built to catch and settle all storm water runoff from the plant. These cost $50,000.
2. Bag-house maintenance and operation were improved. At present, particulate loadings are quite low and the plant normally operates with an invisible plume.
3. The acid plant bag house is being replaced with a hot, electrostatic precipitator. This will cost $1 million.
4. Windblown dust from inside the plant has been identified as the most significant source of lead fallout. A new dust-handling system is being planned and a yard paving program is under way. These will be followed by regular and continuous yard sweeping and washing and will cost $1 million.
5. Improved in-plant ventilation is planned to improve hygiene and reduce inplant dusting. This will cost $500,000.

Finally, the company has established a well-qualified, full time, in-house environmental group to monitor the operations and to work with the agencies and researchers to establish effective pollution control measures.

Turning to the algae problem in the receiving streams below the mine and mills, there are several potential sources of this problem growth:

1. Subterranean mine water, coming out of limestone, 1,000 feet below the surface, contains dissolved carbon dioxide, carbonates etc., in above-normal amounts and can cause problems.
2. Minor oil spills and incorporation of finely ground rock and minerals into the mine water is a problem.
3. Water from the milling process contains finely ground limestone and unrecovered minerals as well as traces of flotation reagents. This can cause problems.
4. Surface runoff water during storms can agitate the ponds and increase rock-flour runoff.
5. The aquatic life balance can be upset by the very presence of a new 100 or 200 acre water empoundment.

All of these can contribute to the problem.

This water study has grown to involve nine mines operated by five companies plus the various university, state and federal agencies. Considerable progress has been made and two possible solutions are being tested:

1. **Recirculation**—The mill water is being recycled but the excess mine water must be overflowed.
2. **Biologic treatment**—A system of artificial meanders was constructed below the tailings dam to provide aeration, residence time, and an environment to grow algae mattes within the property boundaries. These algae mattes then act as filters to trap the very fine overflow rock particles. The matte growth is intended to "use up" the nutrients before they leave the property. After the meanders, a final sediment pond was constructed to

collect any material not deposited in the meanders, and to catch flood-flushed material.

Neither which solution is best nor whether either will answer the problem sufficiently is yet determined. This work continues. The meander test has cost $70,000 to date.

In addition to the algae problem, the university is continuing to investigate possible long-term trace element build up in the flora and fauna in the receiving systems.

It should be noted here that the receiving stream water has been monitored since 1965, three years before start of operations. Water quality, by chemical parameters, continues to be well within accepted standards. The water is clear. Fish have been planted and appear to be thriving in both ponds and in the meanders. But, as stated by Dr. Wixson, we do have an aesthetic problem.

Conclusion

The degree of cooperation in all these efforts has been extraordinary.

The companies have confidence in the study team as an unbiased research group.

The researchers have free access to otherwise restricted mine properties and operations.

They are presenting the facts and *together* we are devising strategies to alter the readings so as to provide positive environmental protection.

Of particular value is our working together to tune-up new control mechanisms. Procedures are not being dictated. When it is evident that something is not working, new procedures are developed. No limit has been set on cooperation, appropriations or information flow. And, there is no atmosphere of threat.

The control measures resulting from this work will be of continued applied value to the mineral industry both in Missouri and elsewhere.

This cooperative program has provided real-world problems that need solution. The university, located 50 miles away, has a wealth of trained researchers capable and happy to work on these practical problems. The program is a fine example of the public getting good value for the NSF-RANN research dollar.

And no one should accuse the companies of getting something for nothing. They have contributed money directly to the university projects. They are contributing a lot of time. And, they have spent considerable time and money in field-testing ideas from the group.

Everyone benefits.

No one questions whether the environment is worthy of our concern. It is. And we are working together to protect it. We are also looking forward to the continued production of the much-needed lead, zinc, copper, silver and cadmium from the New Lead Belt of Missouri.

We need these metals to maintain our standard of living. You can not hide a mine. The practical, common-sense, working partnership, developed in this project has allowed environmentalists to work with industrial engineers to solve these problems and improve production.

We think the Lead Project is indeed Research Applied to National Needs. As we acknowledge the support of this research by the NSF-RANN Trace Contaminants Program, we also extend sincere appreciation to the previously mentioned industries and other Federal and state agencies for their continued support, assistance and participation.

HUMAN HEALTH AND MERCURY

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Baghdad, Iraq

DR. WEISS

A prophetic exchange took place in May 1968 during the First Rochester Conference on Toxicity, which surveyed research on persistent pesticides.

> *Dr. Robert Risebrough (University of California):*
>
> "Why should mercury be a problem in the northern countries rather than here in the more temperate ones?"
>
> *Dr. Fredrick Berglund (Swedish National Institute of Public Health):*
>
> "I think one reason that this problem does not exist in the United States with mercury is that the levels are not known. Although there is a tolerance of zero for mercury compounds in foods in the United States, I feel personally that the problem also exists here as it does in other parts of the world but it is not recognized."

Two years later, Norvald Fimreite, a graduate student at the University of Western Ontario, reported that fish from Lake St. Clair bore dangerously high levels of mercury. His disclosure sparked a frantic survey of contamination in the United States, soon followed by news that fish and wildlife in more than half the states carried excessive levels.

Next came the revelation of Dr. Bruce MacDuffie, State University of New York at Binghamton, that even deep ocean fish such as tuna and swordfish, once thought to be free of contamination, may contain unsafe quantities of mercury. These discoveries flung mercury into front-page prominence.

They also lifted the University of Rochester into a prominent role as a center of research into the health effects of methylmercury. We built on our long experience with mercury and its compounds. RANN, with further support from the Food and Drug Administration and the National Institute of General Medical Sciences, enabled us to strike at the problem from many directions at once, a strategy imposed by our ignorance of its dimensions.

Mercury Characteristics

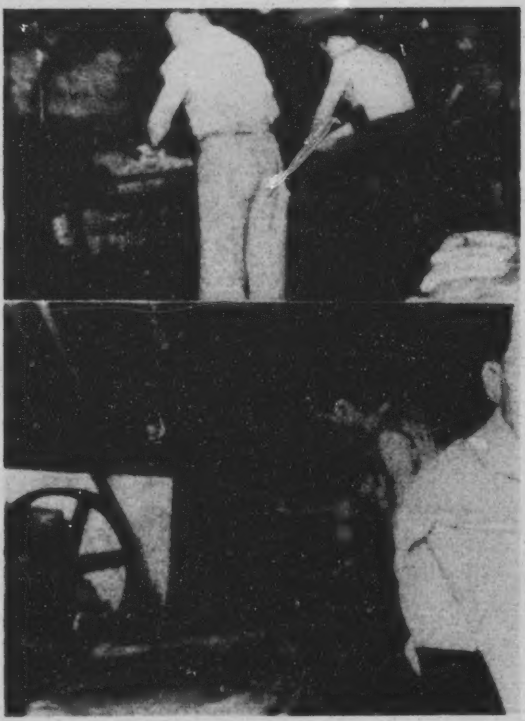
Donald Hunter, the British toxicologist, classifies mercury as one of the "ancient metals." Known since antiquity, this silvery liquid fulfills a variety of practical functions in modern society. The United States alone consumed more than 6 million pounds of mercury last year.

Mercury was recognized as a poison as long ago as 1600 B. C. Mined mainly as cinnabar, or mercuric sulfide, it took such a toll of workers at the mines of Almaden, in Spain, that in 1665 it inspired the first industrial hygiene legislation on record. Now, Almaden is serving as a laboratory for us in studying community effects.

The most frequently noted symptom, probably because of its striking visibility, is tremor. It often was called "hatter's shakes," because so many workers in the felt hat industry showed the symptom, or "Danbury shakes," because Danbury, Connecticut, was the center of the now-defunct industry.

Mercury exposure arose from fur soaked in an acid nitrate of mercury, shown in Figure 1, a process that transformed the smooth straight hair of the animal skins, from which the hats were

Figure 1



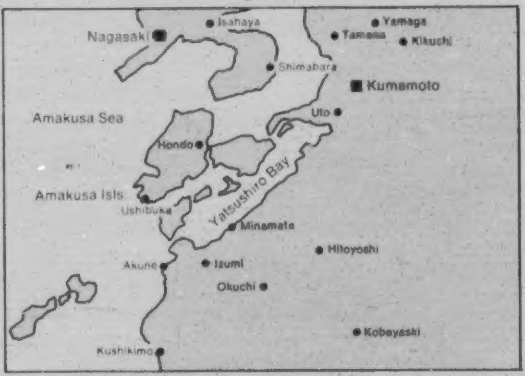
manufactured, into a twisted, rough, limp felt. As this "carroted" fur (so-called because it turned orange) passed through the various states of the manufacturing process, the mercury escaped into the air, exposing many workers to atmospheric concentrations far beyond safe levels.

The current threat, however, encompasses different boundaries, originates from different sources, and evokes a different pattern of toxic symptoms. The mercury problem that provoked the recent headlines, and stirs the concern of toxicologists and responsible public officials, arises from the presence of mercury in food; in particular, an organic compound of mercury known as methylmercury.

Mercury in Food

Nowhere have its ecological manifestations been expressed as chillingly as Minamata Bay, where an entire community suffered disaster. Minamata, on the coast of the southernmost Japanese island of Kyushu, Figure 2, provided the first intimations that organic mercury posed more than a limited threat.

Figure 2



The inhabitants of the area, mostly fishermen and their families, were attacked between 1953 and the early 1960s by a central nervous system affliction that came to be known as "Minamata Disease." Numbness, slurred speech, incoordination, emotional lability, narrowing of vision, and other symptoms marked its victims. The Japanese called it *Kibyo*, or mystery illness, because they could not discover the cause. They did find, however, that the symptoms could be induced in cats by feeding them fish and shellfish caught from the bay.

But it was not until Dr. Douglas McAlpine, a visiting British toxicologist, pointed out the similarity of Minamata disease symptoms to those of organic mercury poisoning that the riddle was cracked. Minamata disease came from eating fish and shellfish contaminated with organic mercury. The search for the source of the organic mercury led the Japanese scientists to a factory that used mercuric chloride as a catalyst to manufacture vinyl chloride. The factory dumped its effluent into the bay. High concentrations of mercury were discovered near the outfall and even at considerable distances from it. Fish and shellfish from the bay were found to contain astonishing levels of mercury, and fishing was banned.

Mercury in oceans, lakes and rivers arises from many sources—some atmospheric, some geological, some industrial. It used to be thought that the mercury from these sources would sink to the bottom and remain there, presumably inert, in perpetuity. Now we know better. Microorganisms in the bottom mud convert the inorganic mercury to methylmercury. As a result, these deposits continue to breed methylmercury, slowly but inexorably, perhaps for hundreds of years. This superb human pesticide disperses in the water, is first taken up by plankton and plants and, becoming more and more concentrated, ascends the food chain until it enters fish such as pike (which also ingest the mercury-laden water itself). The fish will show flesh concentrations thousands of times higher than those of the surrounding waters. And then humans, sitting at the top of the food chain, eat the fish.

Threat Measured

Our program at Rochester focuses on one broad question: How much of a threat to human health is methylmercury?

A key problem to solve is how methylmercury is handled by the body—how it may be transformed chemically, how long it remains, where it concentrates, how it is excreted. All of these questions demand exceptionally sensitive and reliable chemical assays. Our analytical group responded to this demand by developing several new assay methods.

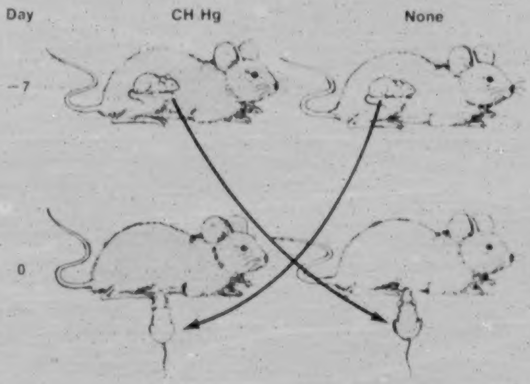
We needed, most of all, a rapid but sensitive method for routine determinations. Taking advantage of the skills of Dr. Lazlo Magos, a toxicologist from Great Britain who was spending three months with our program, the analytical group developed an atomic absorption method at a particularly favorable time. Almost as soon as the task was accomplished, we found ourselves involved in the midst of an epidemic of methylmercury poisoning in Iraq—to be described by Dr. Dhahir. Without this indispensable tool at our disposal, we could have been of little help.

Our analytical group is devoting a significant proportion of its effort to the analysis of hair. Since mercury accumulates in hair with concentrations reflecting the body burden, hair analyses contain an individual's exposure history. Our group now can trace the recent history of exposure in a single human hair. Figure 3 shows hair samples being obtained from a Spanish population exposed to mercury vapor.

Our awareness that the fetus is exquisitely sensitive to foreign chemicals compelled us to make prenatal effects a significant aspect of our program. We need to know how birth defects arise from methylmercury. Figure 4 shows the design of cross-fostering research techniques to enable us to separate prenatal from neonatal exposure. We also need to find out how much methylmercury might be transmitted by nursing mothers, a particular concern of Dr. Richard Doherty. The Iraq episode, particularly, stimulated our interest in this problem since there, as in many traditional societies, children nurse for perhaps two years. Figure 5 shows a team collecting samples in Iraq. At the same time that we've been obtaining human samples from Iraq, we are conducting laboratory studies (mice) in which we can precisely control exposure conditions and other factors. The milking procedure in Figure 6 was developed by Dr. Alan Gates.

Figure 3

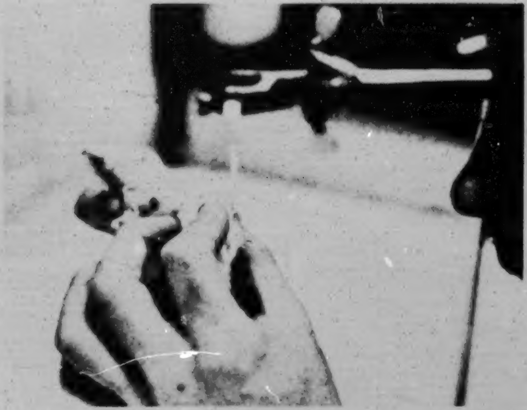
Figure 4—**Experimental Design**



As noted earlier, methylmercury acts on the nervous system, so that its main symptoms are behavorial and neurological. The laboratory of Behavioral Toxicology is trying to determine more precisely what functions go awry, what happens in the brain, and how much methylmercury is required to produce damage. We also are looking

Figure 5

Figure 6

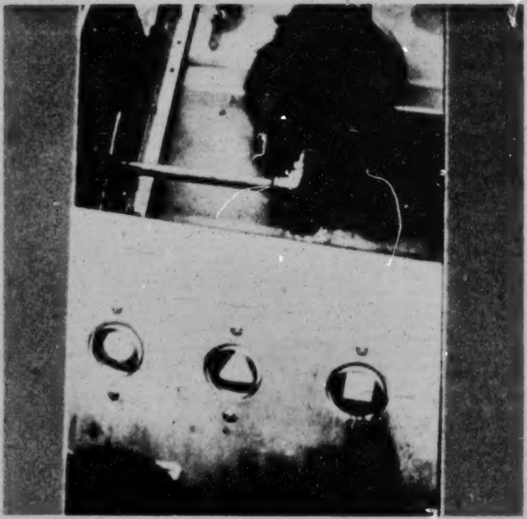


for clues about what kinds of tests could be developed for humans.

One of our experiments with monkeys provided a clue. Dr. Hugh Evans trained monkeys, as shown in Figure 7, to respond to a lighted square, rather than a simultaneously presented circle and triangle. Since methylmercury seems to concentrate in that area of the brain devoted to vision, we devised this test to determine how much exposure was required to produce visual impairment. We also varied the brightness of these forms.

The first symptom we saw after weeks of exposure was a decrease in accuracy at the dimmest level. We think now that this may provide a useful test for assessing the impact of human exposure.

Figure 7



Complementary Efforts

As you can see, our laboratory and field programs closely complement one another. In Peru and Samoa, helped by additional funds from the canning and tuna industries, we are studying populations that may yield clues to consequences of long-term human exposure.

In Peru, with the collaboration of the World Health Organization, we are studying a coastal village whose inhabitants subsist largely on a diet of fish, some of them, such as swordfish and shark, containing methylmercury concentrations much in excess of Food and Drug Administration guidelines. Figure 8 shows how dry this area is, with little other food available than lemons. Even water is trucked in. Figure 9 shows some of the inhabitants, who do not appear at all malnourished. In Samoa, we have access to a population of tuna fishermen who live mostly on fish during their five-month trips to the fishing grounds. Figure 10 is a scene from the harbor.

Therapy is another aspect of our program that profits from the laboratory-field dialogue. Our original involvement in Iraq came about because of Dr. Clarkson's success, in collaboration with Dow Chemical, in finding a resin, that helps clear methylmercury from the body. Although the work was done with mice, the possible extension to humans was seized on by Iraqi scientists and clinicians confronted by mass poisoning on an immense scale.

Figure 8

Figure 9

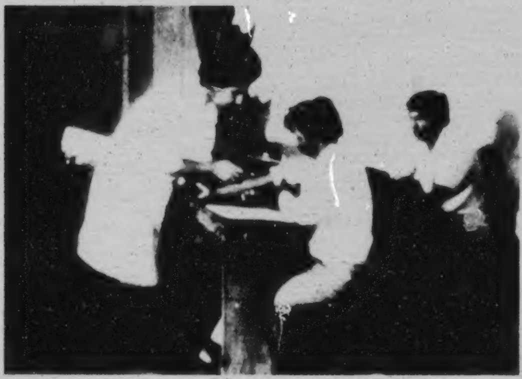
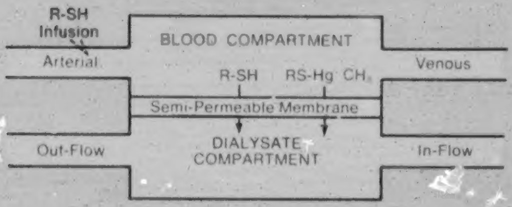


Figure 10

At present, Mr. Paul Kostyniak is examining the technique of dialysis—used with kidney patients—as a way to eliminate methyl mercury from dogs. Successful treatments along the same line have been performed in Iraq. Figure 11 shows a schematic diagram of the process.

Figure 11



The role of the prepared scientist in dealing with societal problems is strikingly illustrated by the Iraq episode, which will be described by Dr. Dhahir.

DR. DHAHIR:

The 1972 epidemic of methylmercury poisoning in Iraq initiated a long-term collaborative program between the universities of Baghdad and Rochester. Studies of the epidemic were begun on an emergency basis in February 1972 when the Iraqi Government called upon the World Health Organization and invited several international experts on mercury. Among those was Prof. Thomas W. Clarkson of the University of Rochester.

This epidemic is the most catastrophic ever recorded in terms of its extent and the resulting morbidity and mortality. A total of 6,530 cases of poisoning were admitted to hospitals in provinces throughout the country, and there were 459 hospital deaths caused by methylmercury poisoning. Figure 1 shows the total in each of the Iraqi provinces of hospital admission and deaths in the epidemic.

Mercury-treated wheat and barley seeds were imported and distributed between September 16 and October 15, 1971. The total amount of wheat and barley distribution was 73,201 and 22,262 metric tons, respectively. Figures 2* and 3 portray the wheat and barley sacks imported for planting.

The seed grain was imported largely from Mexico and thus the name Mexipack is often given to it; some was imported from Algeria. The wheat shipped from Mexico was in Spanish-labeled sacks, and was the source of the flour and bread that was eaten by humans in Iraq. The barley was shipped from the United States in English-printed sacks. Some barley was fed to

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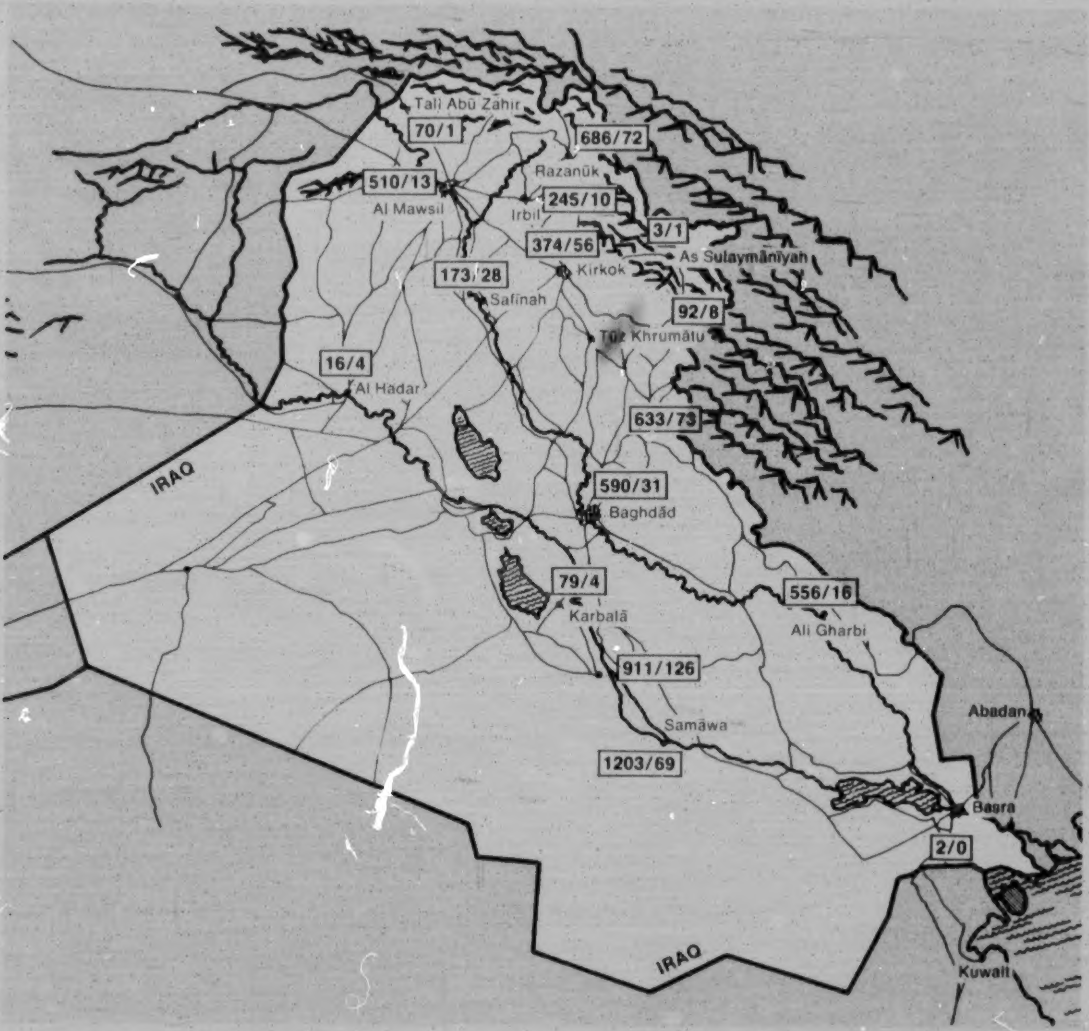
*Provided through the courtesy of M. R. Greenwood.

Figure 1


Tall Abū Zahir
70/1
686/72
Razanūk
510/13
Al Mawsil
245/10
Irbil
3/1
374/56
As Sulaymānīyah
173/28
Kirkok
Safinah
92/8
Tūz Khrumātu
16/4
Al Hadar
633/73
IRAQ
590/31
Baghdād
79/4
556/16
Karbalā
Ali Gharbi
911/126
Abadan
Samāwa
1203/69
Basra
2/0
IRAQ
Kuwait

animals in Iraq, but no problems were noticed. Additional treatment with the fungicide was made to some of the grain in Iraq. Poisoning occurred basically from consuming home-made bread prepared from the treated grain, which was tinted with a pink dye to indicate its treatment with the fungicide.

Some of the farmers thought that by washing the grain and removing the dye the poison would be washed off, too. In addition to this, some were more cautious; they first fed the grain to their animals and when there was no immediate response observed, they assumed that the poison was completely washed off.

The majority of the poisoned subjects were farmers and their families. They baked their own bread in ovens made from mud, such as that in Figure 4.*

It should be pointed out that home-made bread was the source of mercury poisoning and

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*Provided through the courtesy of M. R. Greenwood.

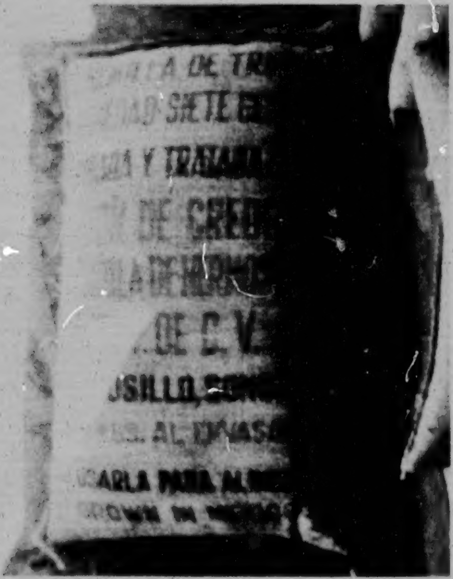


Figure 2

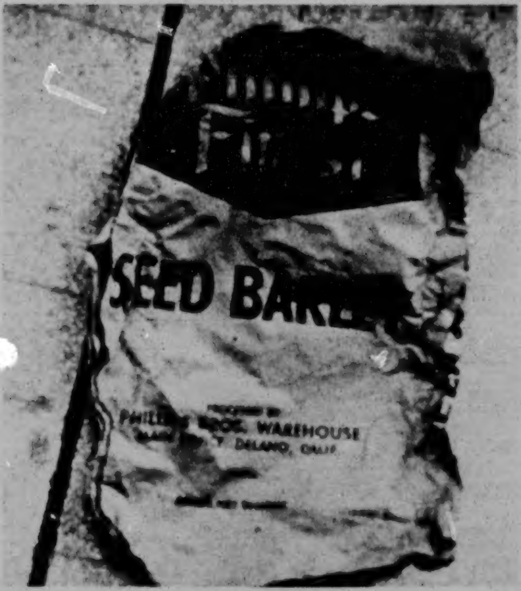


Figure 3

Figure 4

that not a single case of poisoning was recorded in major cities, where bread is prepared from government-inspected flour supplies.

Major Concerns

The major concerns of the authorities were:

1. Control of the epidemic.
2. Prevention of further exposures.
3. Treatment of the exposed victims.

To deal with the first and second phases of the crisis, the authorities took the following measures:

1. They issued stringent warnings concerning the danger of consuming the treated grain.
2. They ordered the return of what each farmer or individual had in his possession of the treated grain and assured death penalty for the violators.
3. They observed daily checking and analysis of flour supplies and bakeries.
4. They prohibited slaughter of sheep and cattle. This measure was taken because of the fear that some of the barley had been fed to these animals. However, analysis of hundreds of meat samples revealed that a very few samples contained slightly high concentration of mercury, but overall were not significant; therefore, the meat was back on the market after three weeks of prohibition.

The first and second phases of the crisis consisted of the control of the epidemic and the prevention of further exposures. After these phases were over and because of the fact that the scientific teams of Baghdad and Rochester were more involved in the clinical side, the study of the hospitalized cases inspired the two teams to adopt a proposal for a collaborative research project on mercury poisoning in Iraq. This project was to be of universal value to the knowledge of man about the hazardous role of this element in our life.

At this stage, the small Mercury Analytical Laboratory became a large unit of Mercury Research Laboratory shown in Figure 5. This unit was first equipped by Rochester's team and later by the University of Baghdad.

This laboratory was responsible for programming the collection and analysis of all biological materials from patients under study. The Scientific Committee supervised all research projects along with its duties as the supreme advisory board formulated by the Ministry of Health and approved by the University of Baghdad to act on all matters concerned with mercury poisoning. The Clinical Committee was responsible for evaluating all the clinical manifestations of the epidemic.

Figure 5

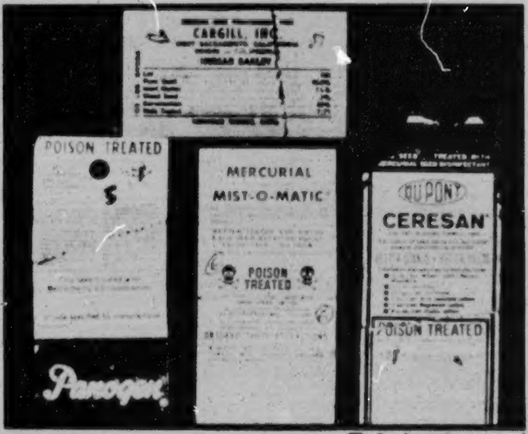
Goals of Joint Effort

The major objectives of the collaborative mercury program between the Universities of Baghdad and Rochester were:

1. To study the clinical manifestations of the epidemic.
2. To assess the pharmacological and toxicological evaluations.
3. To follow up studies on the exposed subjects.

Treatment of the exposed victims was the major concern of the two teams. In carrying out this task, the knowledge about the kind of the mercurial fungicide used to treat the grain was a major factor. At the beginning of the outbreak, it was thought that ethylmercury was responsible for the poisoning. Labels on the wheat sacks such as those in Figure 6 did not give any clue.

Figure 6



Information on the type of mercurial compound used to treat the grain was not indicated on the wheat sacks nor on the labels attached to them. Gas chromatographic analysis of wheat and flour samples, at both the Mercury Research Laboratory in Baghdad and in the Toxicology Center at Rochester, revealed that the major form of the fungicide was methylmercury.

Three mercury-binding compounds used in the course of treatment were D-penicillamine, N-acetyl-DL-penicillamine, and a thiol resin. This is the first study in which the thiol resin has been administered to humans. The U.S. Food and Drug Administration responded to the emergency by granting virtually immediate clearance for the resin.

Methylmercury produces characteristic toxic effects in humans which differ from the toxic effects of other mercury compounds. The primary signs and symptoms of the family in Figure 7 poisoned by methylmercury result from damage to the nervous system and are characterized by loss of sensation in the extremities of the hands and feet and in areas around the mouth (paresthesia), loss of coordination in gait (ataxia), and slurred speech.

Findings

The first Baghdad-Rochester joint publication was an inter-university preliminary report, which was published in *Science*, (Vol. 181, July, 1973).

In this report we described a perspective of the present and future studies, which can be summarized as follows:

- **Observations on and correlation between the effect of methylmercury in the population studied and the total amount of mercury accumulated in the body. Data obtained from the dose-response relationships indicate that the symptoms of methylmercury poisoning become detectable when individuals have accumulated a body burden of approximately 25 to 40 milligrams of mercury.**
- **Methylmercury was identified to be the causative agent of poisoning.**
- **The concentration of mercury in blood is the best indicator of the body burden in people exposed to the poison.**
- **The measure of mercury concentrations in consecutive segments of hair samples is the best means of recapitulating the history of exposure.**
- **Our observations indicate that hazardous amounts of methylmercury can enter the fetus in utero as well as the infant who consumes milk of a mother who has eaten contaminated bread as in Figure 8. Methylmercury is transferred into milk at a concentration equal to 3 per cent of that of the blood.**
- **The clearance of mercury from blood may be accelerated by oral administration of D-penicillamine, N-acetyl-DL-penicillamine, or thiol resin. The efficacy of these agents differs among individuals.**
- **Only a small fraction of the total amount of wheat distributed to the population was required to cause the reported 6,530 cases of poisoning. Less than one half a gram of methylmercury caused poisoning of about 100 subjects. This fact clearly demonstrates that the distribution of 73,201 metric tons of treated wheat carried with it a great potential for human poisoning.**

Figure 7

Figure 8

WEATHER MODIFICATION—HAIL RESEARCH

William C. Swinbank *

Director, National Hail Research Experiment
National Center for Atmospheric Research
Boulder, Colorado

The basic incentive for hail research in this country, and anywhere else for that matter, is the enormous damage hail causes to crops. Damage runs into thousands of millions of dollars over the world as a whole and about one-third occurs in this country. The damage to property is about 20 per cent of that. Although damage is the basic incentive, the immediate stimulus to the present activity in this country has been the successes Russians reported in the 1960s. But their methods of evaluation were questioned since they were based on crop damage claims. People from this country who went to Russia came back only partially convinced about what they saw.

Therefore, the conviction grew in this country that it was time to carry out a properly controlled experiment—not so much to *demonstrate* that it could be done, but to *find out* whether it could be done. This conviction led to the establishment of the present project: The National Hail Research Experiment.

The project is sponsored by the National Science Foundation and is managed by the National Center for Atmospheric Research at Boulder, Colorado. The project was laid out as a five-year field program with a first summer of operation in 1972. It is a cooperative project, coordinating expertise from universities, government agencies and private bodies.

The first thing we had to decide was where to carry out the experiment. The obvious place was the region of most frequent hail occurrence in the United States, namely Northeastern Colorado.

Facilities, Methodology

Figure 1 is an aerial view of our site headquarters at Grover in Northeastern Colorado containing the most sophisticated and advanced array of equipment for hail research that has ever been assembled. We have multiple radar facilities, for example. And, unlike the Russian approach, we are carrying out a randomized statistical experiment to learn the effects of cloud seeding on hail formation. In this experiment we alternate hail days on a random basis between seed and no-seed days in an area outlined in Figure 2. By measuring the hail fall on the ground, we will arrive statistically at an evaluation of whether the suppression technique has been successful.

Figure 1

Now, the hypothesis on which this suppression technique, and indeed all suppression techniques throughout the world at present are based, is that, as the air ascends, it cools. It condenses water and this water is shared among the available hail foci in the cloud or the natural freezing nuclei. When these natural freezing nuclei or hail foci are numerous, the competition for the available water is intense and the hail stones that are formed are correspondingly small. As they fall through the cloud, they are so small that they melt before they reach the ground and form harmlessly as rain.

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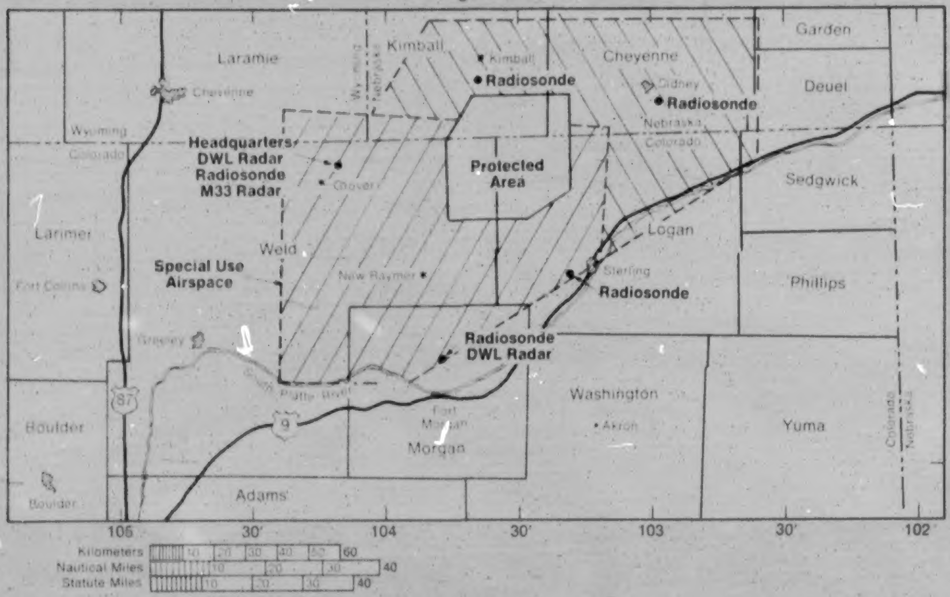
* Dr. Swinbank died December 28, 1973.

Figure 2


Laramie
Cheyenne
Wyoming
Colorado
Wyoming
Nebraska
Kimball
Kimball
Radiosonde
Cheyenne
Sidney
Radiosonde
Nebraska
Colorado
Garden
Deuel
Headquarters
DWL Radar
Radiosonde
M33 Radar
Glover
Protected Area
Sedgwick
Larimer
Weld
Logan
Special Use Airspace
New Raymer
Fort Collins
Sterling
Radiosonde
Phillips
Greeley
Radiosonde
DWL Radar
South Platte River
87
9
Washington
Akron
Fort Morgan
Morgan
Boulder
Yuma
Colorado
Nebraska
41
40
Boulder
Adams
105
30′
104
30′
103
30′
102
Kilometers 10 20 30 40 50 60
Nautical Miles 10 20 30 40
Statute Miles 10 20 30 40

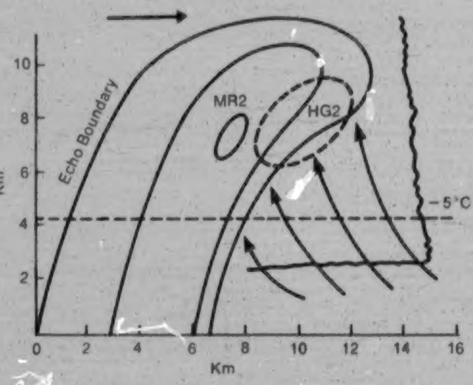
However, if the natural foci, or freezing nuclei, are few in number, the competition for the available water is less intense and the number of hail stones formed is fewer. They therefore are correspondingly larger. These large hail stones fall, are able to resist the melting process and reach the ground as damaging hail.

On this hypothesis, therefore, the evident way in which one would proceed to prevent the occurrence of these large damaging hail stones is to supplement the natural supply of freezing nuclei with artificially introduced nuclei. The most efficient nucleus known is silver iodide. The question of how best, most efficiently and frequently artificial nuclei should be seeded into clouds is addressed in Figure 3.

In this schematic, vertical cross-section of a hail storm, the visual outline of the cloud is shown. The intense interior part of the cloud as revealed by radar is shown by the internal contours. There is a certain level of reflectivity that becomes more intense further into the cloud. The central oval is the region of maximum reflectivity, or MRZ. Here, it is postulated, is the hail growth zone in the cloud. An updraft feeds the cloud, not only with air but with all the micro-physical content that determines what goes on in the interior of the cloud.

We inject nuclei into the cloud by flying an aircraft at cloud base in a very particular position on the updraft. This aircraft projects vertically a specially designed rocket at an altitude below the cloud where the temperature has a level of

Figure 3


Echo Boundary
MR2
HG2
−5°C
Km
10
8
6
4
2
0
2
4
6
8
10
12
14
16
Km

minus 5° centigrade. We have chosen this temperature for technical reasons as the best level at which to inject the nucleant. The missile each time injects 100 grams of silver iodide in the form of powder so fine that one gram of silver iodide produces something like 10^{16} nuclei. These silver iodide particles, having been injected at this point and carried by the updraft further up into the cloud, become diffused. Having got into this hail growth zone, they then compete for the available water. We hope there will result from that competition a large number of small hail stones; which will then subsequently melt on the way down and reach the surface as rain.

Tentative Findings

In the first two years of a five-year field program, we feel it premature to talk very much about results. The bare results that we have so far achieved are from 28 hail days in the past two years—equal numbers of which were seed and no-seed days. On the average, the hail fall has been reduced by 50 per cent on the seed days compared with the no-seed days. However, the phenomenon we are examining is so variable that the result has a significance level of only 30 per cent. That is, the results we already have stand only seven in ten chances of being right in the final outcome. We have three chances in ten of being wrong.

We hope of course that, as the project progresses, this significance in our result will get fined down to something like the 5 per cent level so that at the end of the project we can say with a greater degree of conviction what we have achieved.

The Russians claim typically 80 per cent success. And, although with no greater economic incentive they are spending something like 20 times as much as this country on hail work, they concede they do not understand how the success they claim is brought about.

We in this project feel that we must understand—if we are successful—why we are successful. The reasons for wishing to understand are two-fold:

1. If we achieve some success in hail suppression, we would find it unsatisfactory as scientists to have done something we did not understand.
2. More practically—if we are successful and we wish to transfer our techniques to other regions where the storms may be different in nature, we can do this properly and efficiently only if we understand why what we have done has worked.

For this reason the project has a dual emphasis. There is an emphasis on the suppression that I have discussed. There is an *equal* emphasis on the research aspects. We are carrying out intensive research on the natural behavior of storms, on the behavior of seeded storms supported by laboratory experiments. Thus at the end of the five-year project we hope to have a much better understanding of why storms behave as they do and, if they behave differently when they are seeded, why they behave that way. Of course, we believe a better understanding of the storms might lead to alternative methods of suppressing the hail. We already have certain ideas but we can not go further with these until we get a better understanding of how the storms work.

As a result of our two years' work, we think we can claim a small number of successes.

We believe, for example, that the very design of the experiment (which I think is what the Russians really wish they now had) is such as to lead to an answer to the question can hail be suppressed in the shortest possible time.

The rocket that I mentioned is in fact a major development. It is a spin-stabilized rocket that had to be made out of non-metallic material. This presented many problems. We think we have now solved all of them and have a viable, new suppression tool in the form of this rocket.

Again, we have managed in our research project to penetrate the interior of these severe, convective storms by means of a specially-armored aircraft, in a way that never has been done before. This aircraft has penetrated severe storms more than 100 times and has produced information never obtained before. The information is helping to solve some of the mysteries of what has gone on in that hitherto-unexplored severe convective cloud.

We have developed a rather sophisticated instrument for accepting the mixed rain and hail that falls, separating the two and giving us an immediate, automatic measure both of how much hail, and of how much rain fell over the area that we are trying to protect from hail.

Lastly, the results I have just cited—tentative though they may be—suggest some success in our attempts to suppress hail.

MANAGEMENT OF TEXAS COASTAL RESOURCES

E. Gus Fruh
Center for Research in Water Resources
Environmental Health Engineering Laboratory
University of Texas at Austin

and

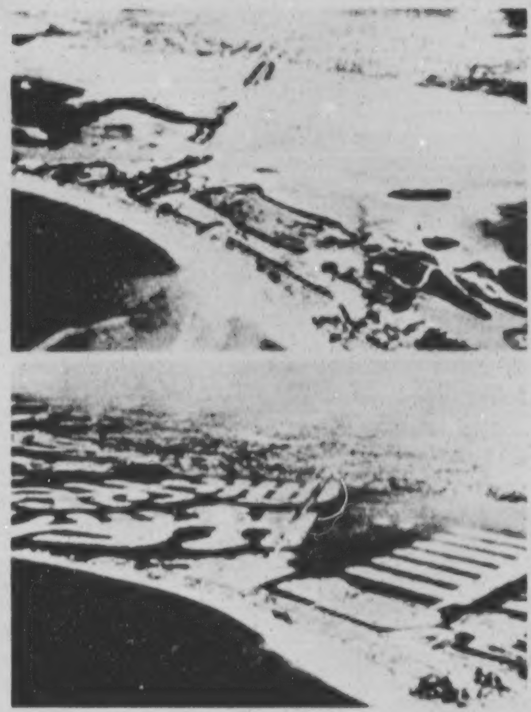
Joe C. Moseley, II
Executive Director, Texas Coastal
and Marine Council
Austin, Texas

The objective of this research project is to develop the methodology and criteria by which the economic, environmental and resource impacts of various proposed Texas Coastal Zone management policies can be assessed.

To many, the "coastal zone" might just be a narrow strip of land where the sea and the land play out their drama. To others, the term "coastal zone" may have other meanings depending upon their particular disciplines. In this project the definition of the term varies according to the policy that must be considered. The term is not limited to a narrow geographic area. For instance, the municipalities, industries and agricultural pursuits along the Texas Coastal Zone require fresh water. Also many organisms that utilize the estuaries after spawning in the Gulf of Mexico require a salinity gradient, which is dependent upon the freshwater inflow. However, the fresh water in the Texas Coastal Zone during the summer is actually the return flows from cities, such as Dallas and San Antonio, which are hundreds of miles inland from the Gulf.

Why do we need to assess management policies along the Texas Coastal Zone? Principally because we have conflicting uses, many of which generate short-term impacts that are undesirable to a considerable segment of the public. Other uses have unknown long-term implications. For instance, 20 years ago many bays and barrier islands along the coastline were unoccupied as shown in the upper picture of Figure 1. Now portions of some bays have been filled for development of finger-type community developments and the barrier islands are markedly changed as can be seen in the lower picture.

Figure 1



During these 20 years, the economy of the Coastal Zone certainly has been stimulated by these construction activities. However, there have often been detrimental effects on the commercial fisheries in addition to the beaches, the sport fish nursery and wildlife areas as well as the natural beauty of the coastline, on which much of the tourist industry depends (Figures 2 and 3). Further-

Figure 2

Figure 3

more, the dunes on the barrier islands have been destabilized by unwise construction practices through the destruction of the sparse but binding vegetation that Nature provides. Hence, these dunes no longer provide natural protection against hurricane wind and waves. Considerable public revenues must be spent on artificial protection of Gulfshore homes and utilities (Figure 4). Similar difficulties arise with location of industrial sites, deepwater ports and developing or enlarging navigation channels (Figures 5 and 6).

Development of the Project

How did this project come about? The initiative came from the public in the Coastal Zone and some of the elected representatives. They realized that large scale undesirable economic and environmental and resource impacts had occurred in the past due to unwise state and local policies and that without effective planning such impacts would occur more frequently in the future. The state government was an effective mechanism for action since all of the submerged lands along the coast out to three leagues are state lands. A part of these state lands had been sold in the past to navigation districts at one dol-

Figure 4

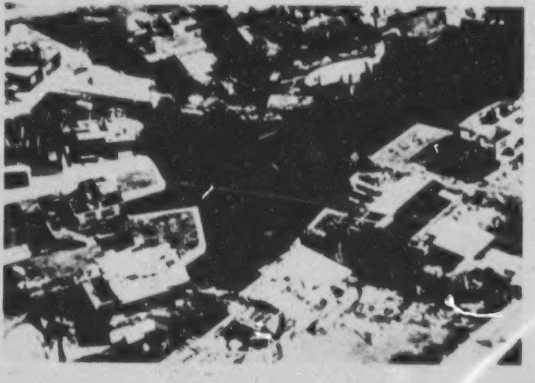


Figure 5

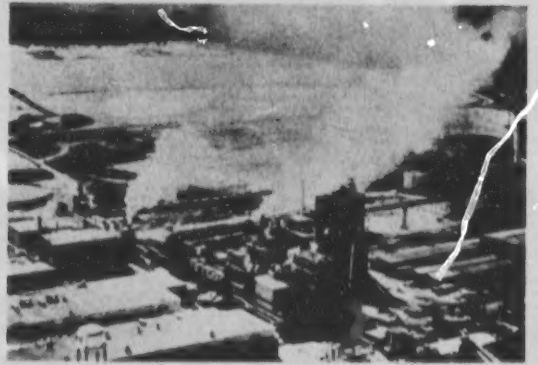


Figure 6

lar an acre. The navigation districts in turn sold or leased the lands to industrial and community developers at considerably higher prices. The Texas Legislature in 1968 placed a moratorium on such sales. In addition, the Legislature instructed the Division of Planning Coordination in the Office of the Governor to utilize the Interagency Council on Natural Resources and the Environment to coordinate the endeavors of various state agencies to develop a coastal resources management program. An interim report was due in December 1970 and a final report in December 1972.

Subsequently, the Governor's office requested the University of Texas at Austin to develop an interdisciplinary research team with significant experience in the Texas Coastal Zone. The team was given the assignment to develop methodology and criteria by which the economic, environmental and resource impacts of any proposed state policy might be assessed. Following preliminary conceptual and qualitative investigations funded by the state, NSF-RANN became interested in the project as a model to be followed by other coastal areas. Beginning in June 1972, the state funding was supplemented by RANN support.

Managing Scheme

What has been the approach? First, the large amount of economic, environmental and resource data available for the Texas Coastal Zone needed to be assessed utilizing tools already operational in state agencies. Although some gaps would no doubt appear in the data base, the interdisciplinary team undertook to utilize its professional experience to estimate the probable trends. Such data gaps were to be detailed by the team, however, so that the state would have a basis on which to decide on future research efforts. The assessment tools were limited as much as possible to proven techniques in use by state agencies, so that the implementation of results obtained by the interdisciplinary team would not be delayed by any necessity to transfer new technology.

The Bureau of Economic Geology is a university research institute that also functions as the state geological agency. Previously, the Bureau had mapped the Texas Coastal Zone in terms of approximately 150 environmental units based on their physical, chemical and biological properties. An interdisciplinary team led by Dr. William Fisher of the Bureau considered these environmental units in the light of both existing and potential major use activities. In this consideration, 34 resource capability units were outlined. Another task force from the Marine Science Institute under the direction of Dr. Carl Oppenheimer further defined the biological features of certain of the capability units—in particular the water quality criteria specific for Texas estuarine organisms.

The Office of Information Services in the Governor's Office previously had developed a state input-output economic model. This model made it possible to estimate for a particular economic sector the effect of a change—not only with regard to sectors that buy or sell directly to the affected sector, but also the indirect and induced effects. Dr. Jared Hazleton, an economist in the Lyndon B. Johnson School of Public Affairs at the University, utilized OIS "software" by which a much smaller region can be "broken out" of the state model. Dr. Kingsley Haynes, a geographer in that school, developed spatial population prediction techniques to estimate land use patterns within a region, particularly for households in an urbanized area.

With the use of the resource capability units previously described, the locational effects of residential and industrial developments are assessed. Additional impacts result, however, from wastes discharged into the environment. Dr. Joseph Malina of the Environmental Health Engineering Program obtained wastewater, air pollution and solid waste loadings from various local, state and Federal regulatory agencies. Inconsistencies were eliminated wherever possible. A data retrieval system and an urban runoff model were developed. In similar fashion, Dr. Frank Masch of the Center for Research in Water Resources utilized estuarine circulation and "conservative substance" transport models obtained from the Texas Water Development Board to develop "reactive substance" transport models.

The Coastal Bend Council of Governments and State Planning Region, a 13-county area centered at Corpus Christi, was selected to serve as a "model" region for the Texas Coastal Zone. This region's economic and physical characteristics are representative of the Texas Coastal Zone. Sufficient data are available from governmental and other sources to minimize "data gap" difficulties. Local and regional agencies are cooperating extensively. In addition, this region will lack adequate fresh water to fulfill its future demands.

The following example illustrates the utilization of the above-described techniques, calibrated specifically for the Coastal Bend region.

Impacts of Power Plant Cooling Systems

One portion of the project was an examination of alternative public policies on power plant cooling and growth. This was undertaken early in the effort to do two things:

1. Demonstrate the feasibility of this method of examining alternative public policies analytically.

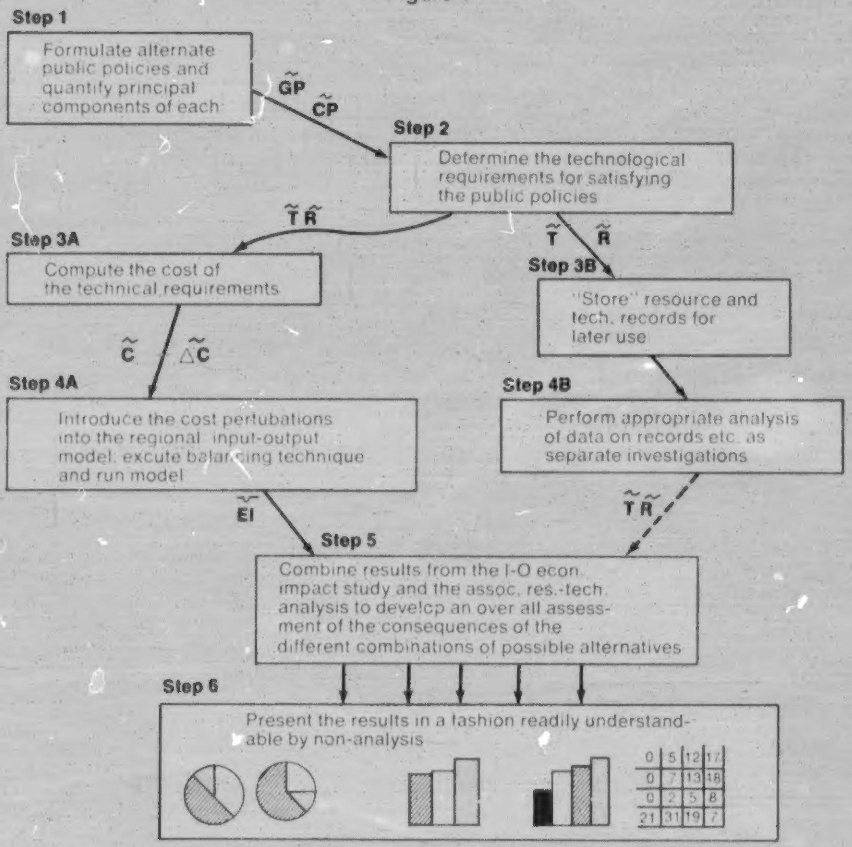
2. Serve as a "cutting-edge" for subsequent efforts by revealing the type of difficulties apt to be encountered in such an effort.

The analysis was made easier by the fact that one electric utility services the entire Coastal Bend region.

In Figure 7, the generalized analytical procedure is illustrated with its six principal steps. Each step is numbered and the boxes summarize what is done. Possibly the most critical, and most frequently overlooked steps are those numbered 1 and 6. The first involves the transformation of public policy statements into a quantitative form to trigger the analytical procedure. The last is the conversion of the analytical results back into a simplified form readily understood by non-analysts. If these steps are not properly done, the chances of the results being accepted and utilized are greatly decreased.

Two types of public policies were simultaneously examined: growth and power plant cooling. Three levels of each were examined; this produced nine combinations or nine alternative futures at any point in time.

Figure 7


Step 1
Formulate alternate public policies and quantify principal components of each
$\widetilde{GP}$
$\widetilde{CP}$
Step 2
Determine the technological requirements for satisfying the public policies
$\widetilde{T}\,\widetilde{R}$
$\widetilde{T}$
$\widetilde{R}$
Step 3A
Compute the cost of the technical requirements
Step 3B
"Store" resource and tech. records for later use
$\widetilde{C}$
$\widetilde{\Delta C}$
Step 4A
Introduce the cost pertubations into the regional input-output model, excute balancing technique and run model
Step 4B
Perform appropriate analysis of data on records etc. as separate investigations
$\widetilde{EI}$
$\widetilde{T}\,\widetilde{R}$
Step 5
Combine results from the I-O econ impact study and the assoc. res.-tech. analysis to develop an over all assessment of the consequences of the different combinations of possible alternatives
Step 6
Present the results in a fashion readily understandable by non-analysis
0 5 12 17
0 7 13 18
0 2 5 8
21 31 19 7

The three growth policies were:

1. ZPG—"Zero population growth," which assumed the growth rate would soon stabilize.

2. CoC—"Chamber of Commerce" prediction, which was an extrapolation of past trends.

3. Int—"Intermediate growth," which was midway between the ZPG and CoC policies.

The three cooling policies considered were:

1. C_1—Continuation of "present practice," i.e., the same mix of once-through ponds and towers as now in use.

2. C_2—"Zero discharge," which assumes that by 1985 there will be no heat added to the aquatic environment by power plants.

3. C_3—"Constant B.t.u. discharge," which assumes that the existing waste heat load will be constant in the future.

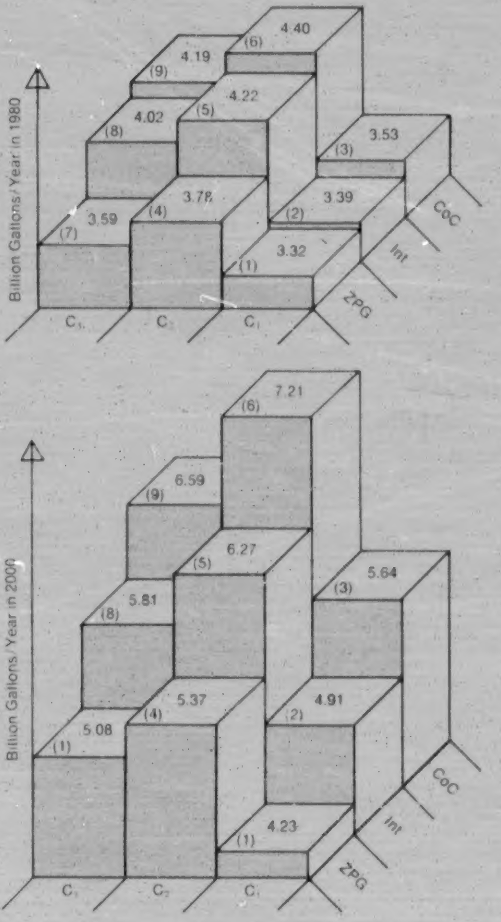
After the three levels of each policy were established, it was necessary to develop technical strategies for implementing each. For example, various combinations of cooling techniques had to be devised to meet the conditions established by each policy alternative. Once this was done, it became a straightforward matter to compute the resource requirements and dollar costs required to meet the conditions of each alternative future. The dollar costs were used to assess the economic and socio-economic impacts, and the resource requirements were saved for later examination. The next, and final, step was the identification and evaluation of the impacts and implications that these resource and dollar costs held for the region.

The consumption of natural resources can be a major factor, as shown in the next four figures for the years 1980 and 2000. Consumptive water use is shown in Figure 8 and total water throughput in Figure 9. The consumptive use for the CoC policy in 2000 exceeds 7.2 billion gallons per day. In a water-scarce area, such as South Texas, this amount of fresh water may not exist, or if it does, there are other prior uses that will preclude its use for cooling.

Land requirements, such as those shown in Figure 10, may be a controlling factor in some areas, although in this case ample land is available in South Texas.

Some cooling options consume significant quantities of energy, as shown in Figure 11. As energy supplies get scarcer or more expensive, this can become most important.

Figure 8



Both capital costs and amortization of capital plus operating costs can be calculated. Assuming that these costs will be passed along to purchasers of electricity in the form of increased rates, it is possible to evaluate the resulting impact on the overall economy. The key to this assessment is a detailed input-output model. Cost increases are entered as percentage increases in the utility sales row and these are distributed proportionally among all purchasers of electricity. A typical transaction table with the

Figure 9

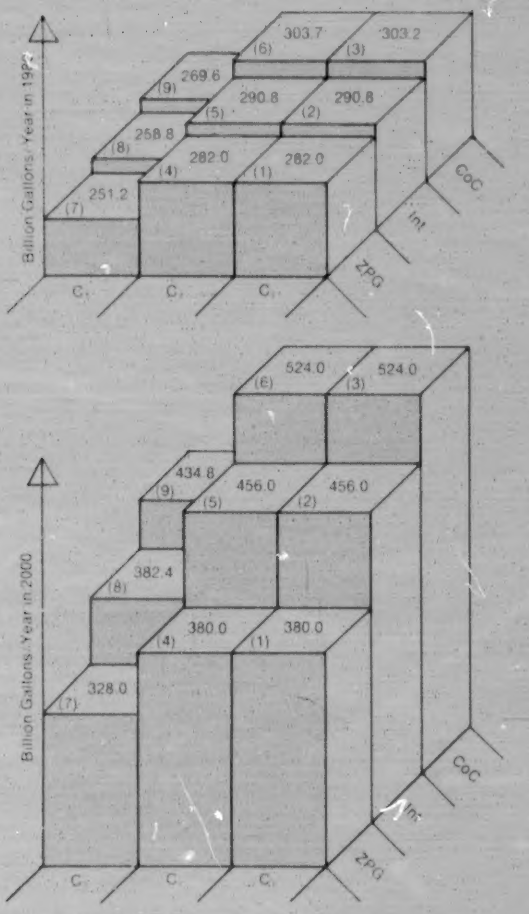
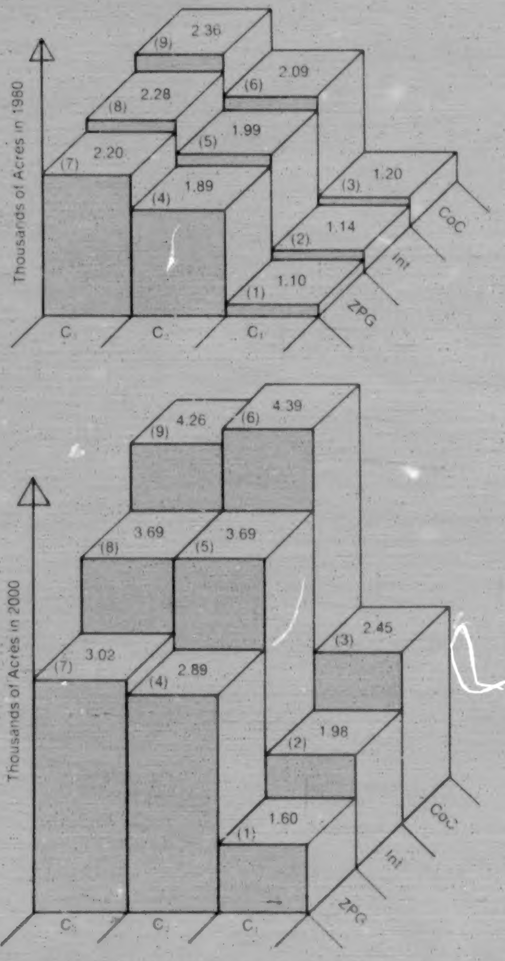


Figure 10

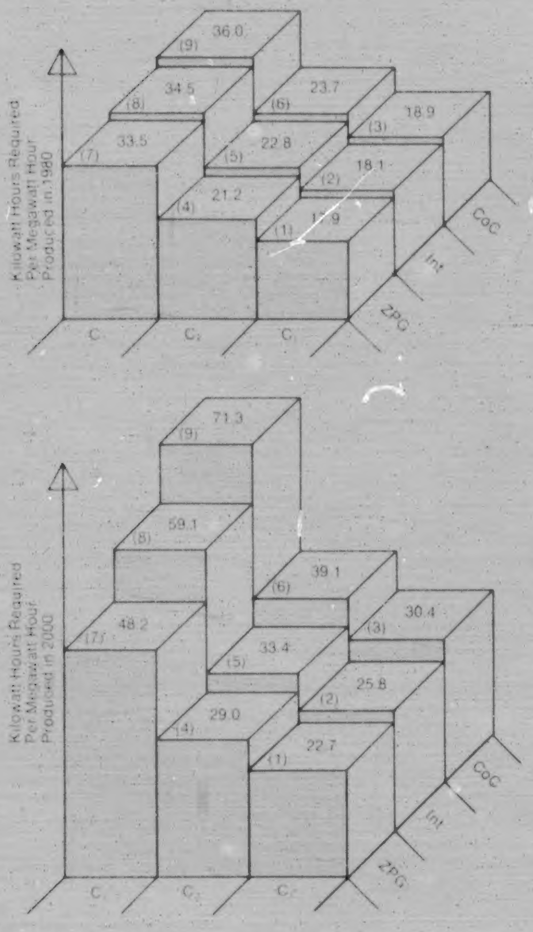


procedure for tracing rate increases is shown in Figure 12. The incremental increase in the cost of electric power that the more expensive cooling policies will have over the least expensive policy, C_1, are shown in Figure 13.

Once these added costs are passed on to the subsequent customers, it is necessary to postulate how they will react to the increased costs. In this study it was assumed that increased costs would be paid from discretionary income or residuals. For business this includes earnings, contributions to profit, payments to stockholders, etc. For households it is simple savings.

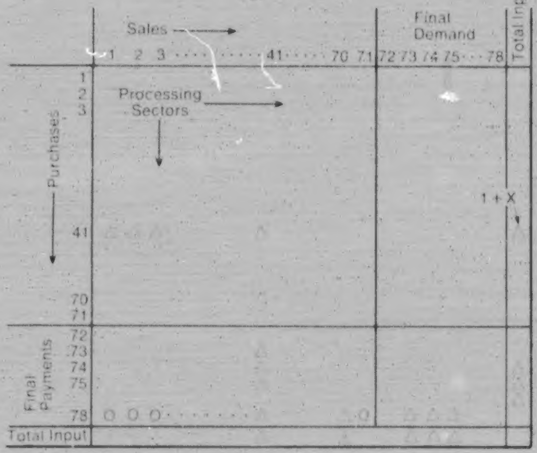
Households, the "ultimate consumer," will feel two pinches. First, there will be a direct cost increase as the monthly electric bill goes up. Second, there will be an indirect cost increase as the price of the many goods and services purchased by the household reflect the increased cost of electricity. The percentage decreases in household residual incomes resulting from different cooling policies are shown in Figure 14.

Figure 11



Translating the values for various cooling policies into dollars per family per year and comparing these dollar figures to some regional norm is most enlightening. These costs are shown in Figure 15. It is seen that for the C policy, this will amount to approximately $74 per family per year by 2000. (All values are in 1970 dollars.) While this may not seem like much to many readers, it just happens to equal the average monthly rent of all families in the 13-county study area. In other words, requiring zero-discharge on power plant cooling only, would cost the average family

Figure 12


Sales
Final Demand
Total Input
1 2 3 ········· 41 ····· 70 71 72 73 74 75 ··· 78
1
2
3
Processing Sectors
Purchases
41
70
71
1 + X
72
73
74
75
78
Final Payments
Total Input

Sector Key
41 Electric Utility
70 Education
73 Govt. Federal
74 Govt. State
75 Govt. Local
78. Residuals (Savings)
△ = Increase
○ = Decrease

Figure 13

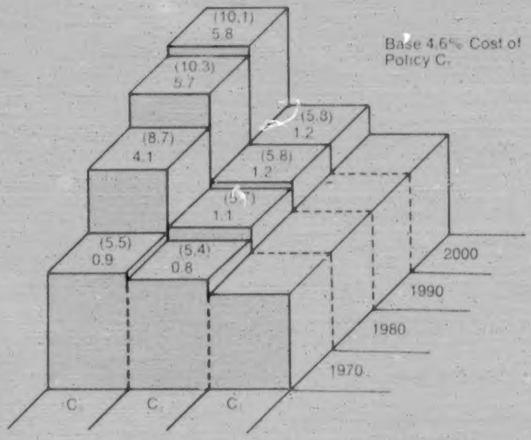


Figure 14

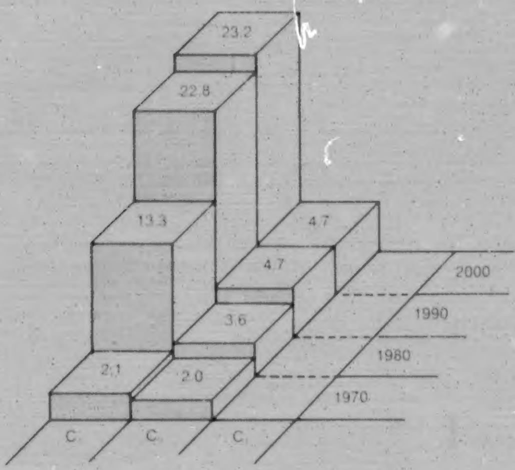
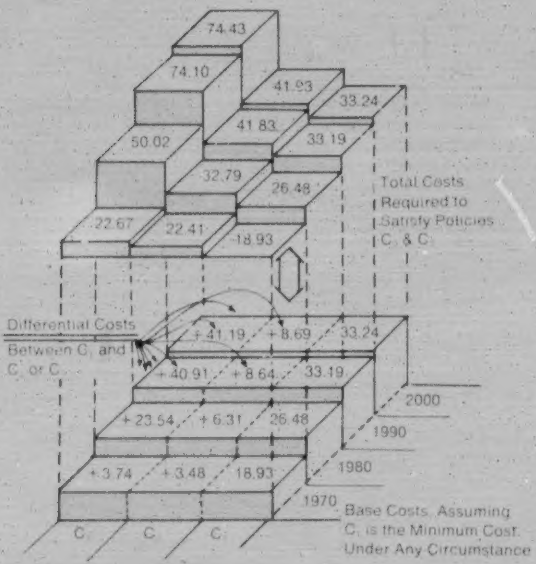


Figure 15



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one month's rent each ye[illegible] Obviously, if the same zero-discharge polic[illegible]re implemented for all wastes the cost would [illegible]uch higher. Similar analyses were applied to[illegible]e many other sectors of the economy, and a n[illegible]ber of other enlightening circumstances were [illegible]vealed.[1]

The implications of the above results should be obvious. There should be a careful analysis of all possible implications of public policy actions before the policy decisions are enacted. This example demonstrates that such analyses are possible and that they can produce information which is meaningful to those officials responsible for policy decisions.

Continuing Work

The objective in the second year of the project is to evaluate the economic and environmental and resource impacts of three hypothetical but somewhat extreme policies on the Coastal Bend region. Subsequently, it will be possible to compare these impacts so that the public and its elected representatives can have some quantitative estimate of the available range of futures. The first alternative assumes that 1970 environmental regulations affecting air and water quality and land use would be applicable in 1980 and 1990. Thus economic and community development would occur with conventional treatment schemes and little hindrance to utilization of lands that are important to the productivity of the estuary or to agriculture. The second policy to be evaluated is somewhat similar to current laws on waste water treatment requirements concerning best available economic treatment and "no discharge" except that the applicable dates are 1980 and 1990. Other assumptions also are made so that the problem reflects conditions in the Coastal Bend region as closely as possible. The third hypothetical policy is the "tape measure" approach. What are the impacts after 1980 if for environmental reasons no development is allowed within 1500 feet of the shoreline?

Further work will be aimed at developing criteria for a policy that allows industrial and community development according to the environmental and economic carrying capacities of the region. The carrying capacity of any environment will dictate the amount of changes due to man's activities that it can absorb without disrupting its ecological balance. Thus, certain activities may be detrimental to an environment. But by contrast it may be that a certain environment (for example, a highly eroding shoreline) is detrimental to a given activity. Natural carrying capacity becomes a baseline expression of the attributes of an environment or resource in terms of specific use activities. Clearly, the natural capacity of an environment may be enhanced through engineering or technology in such a way that a specific activity can be undertaken consistent with an ecologic balance. Management alternatives such as zoning or prohibition of certain activities arise only when the natural carrying capacity is unknown or where the technological enhancement is too costly to the developer or to the regional economy. In many cases, public investments are needed to make specific Gulfshore areas suitable and desirable for further investment. Often, however, the question is not asked in such evaluations whether these investments are ever recaptured by public revenues (either direct or indirect) generated from these community and recreational developments.

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[1] Full report is available from the Center for Research in Water Resources, University of Texas at Austin.

State Utilization of Results

The state has utilized in various ways the results of various stages of this research project. The resource capability unit concept was especially helpful in support of one of the major uses, the passage of state coastal management legislation. Another was in the evaluation of alternative state energy allocation policies. The Texas Offshore Terminal Commission has employed elements of these analyses in its evaluation of a superport for the state. Currently, the Texas Coastal and Marine Council is utilizing parts of the technique to study the problem of fresh-water inflows to the bays. Still another use is that of the General Land Office in developing management plans for the state's 4.5 million acres of submerged coastal lands.

Additional applications are certain to materialize. It is instructive to emphasize an important point. To term the effort a success it is not necessary that all of the techniques developed in an effort such as this be utilized on any single problem. Except in an abstract sense, the institutional realities of the world in which we all operate in fact invariably preclude "comprehensive planning and management." Nevertheless, having such overall analytical capability does help a coastal zone manager to gain better perspective and insight into what he is trying to accomplish.

POLICY ADDRESSES

RANN AND NATIONAL RESEARCH

Dr. H. Guyford Stever
Director
National Science Foundation
Washington, D. C.

It is a pleasure to be with you at the midpoint of this important two-day symposium. (I notice that my remarks follow sessions on disaster mitigation and environmental threats—two subjects that Al Eggers feels should be discussed before every good dinner.)

It was almost four years ago that a new program, with the unlikely acronym of IRRPOS and the unwieldy title of "Interdisciplinary Research Relevant to Problems of Our Society," was born at the National Science Foundation. Not many in Washington or around the nation heralded that birth with much fanfare. And even in the Foundation there were probably a good many raised eyebrows upon learning of this new research upstart with the strange name. Well, that was four years ago—and from what we are seeing at this symposium things have changed. In saying this, however, I am not just referring to the growth of the program and its evolution into RANN—Research Applied to National Needs. That is a story well known to you.

What has happened—and what is of great importance to this country—is that in a period of relatively few years we have rediscovered and begun to put to work in new ways and on new problems, powerful forces that have served us so well in the past. Those forces we know are science and technology. Those new problems are now looming larger than ever. But with those new ways I am confident we are gong to meet the problems and deal with them successfully.

World Leadership

I want to discuss the problems briefly and our potential for solving them. I want to try to put into perspective where we stand and where we are headed in applying science and technology to national needs. To do this, I believe it is necessary to make clear at the outset that this country still has a healthy and powerful science and technology capability. It is true that in recent years there has been concern over the growth of its support. And we have had some disagreement among ourselves about levels of support and priorities involving the various fields of research and development. But past stringencies and differences notwithstanding, this nation is still the world leader in science and technology. There are few fields of science and engineering in which we do not excel or could not make significant new strides should we turn our talent and resources to them.

I do not say this as an advocate of some new kind of science chauvinism, but because the facts bear me out. And it is time that we reaffirm our self confidence and self esteem in our science and technology capability as an essential first step in moving in the direction we must move, in doing the job we must do. I believe strongly that we can do this and that the nation is going to depend on science and technology for greater help in the years ahead.

New Demands

Before turning to how we are accomplishing this, let me say a few words about the new demands being placed on us and their significance to science and society. Being in the midst of these demands today and hearing about them individually as we do through reports in the press, in our offices, and from our friends in the field, we get the impression that we are being bombarded with a series of individual problems, coming as they are one after the other, heaping insult on injury.

A degraded environment.
An energy crisis.
An impending materials shortage.
Rising food costs.
A slowdown in productivity growth.
Increasing competition from abroad.
Urban problems at home.

The list seems endless, the problems unrelated, the challenges insurmountable. They are none of these. The problems, while intensive, *can* be defined and the relationships between them drawn. And most important, they *can* be solved, given the will and dedication necessary—which I think this country *is* capable of mustering.

It is particularly urgent that we grasp the big picture of what is taking place today, and that the public be made fully aware of it, just as it is being made aware today of one of its aspects—the energy dilemma. The public must be given information that will let it realize that what it is seeing as individual problems are also symptoms of a larger problem we must be geared to face. That is, that our rapidly growing technological civilization is now a huge complex system that, in its present operating condition, is straining its environment and overtaxing its available resources.

Limits to Growth?

Much will have to be done by science, technology, industry, and governmental and educational institutions to revise, readjust, and revitalize the system if it is going to survive and function smoothly. It is not that we are bumping up against the limits to growth. But we have reached many of the limits of doing business in the same old way. If we wish to grow and prosper from this point on, we will do so mainly by changing many of our ways technologically and sociologically. For, ultimately, growth in a closed system—as we are finally realizing this planet earth to be—can be accomplished only by a great stretch of human creativity and cooperation, by expanding and applying knowledge to do more and more with relatively less and less, by improving efficiency, eliminating waste, and by greatly reducing environmental impact.

To accomplish this will require not only significant technological advances, but a substantial reordering and reorganization of human activity—of our institutions and behavior. The essence of this is that we must learn to manage change. The technological environment we have created demands this higher degree of adaptability and responsiveness. The current energy situation is a case in point. But it is also an object lesson that our future responses to the need for change must be much more sensitive and timely. We must anticipate, plan, and work far in advance of impending problems.

I know that there are many in this room and attending this symposium who have long shared that belief, but it is a difficult belief to sell. Few are inclined to save for a rainy day as long as the sun shines brightly and the forecast is for extended good weather.

Earlier today a reporter asked me how it was that the energy problems sprang on us so quickly. I was proud to point out that three Science Advisers ago an energy program was started, and a book published in 1965. Almost every word you hear about energy today is in that book. Two Science Advisers ago, a second group started an energy study. The results, now coming out in parts, are greatly affecting the current situation. The fact is that somehow we failed to get the message across in the sunny weather we had at that time.

Interrelationship Evident

Fortunately, we do have people and programs that see the big picture, that recognize the directions in which we must move and move rapidly. Certainly, a program such as RANN fosters an awareness of this. It may be considered as one pioneering effort in combining the technological and social factors necessary for a new systems approach.

The RANN program recognizes that while the problems it is dealing with—such as the energy, environment, and productivity situations being covered at this symposium—are not new, they have grown to the point where the interrelationship among them is more evident. It recognizes that there is an interconnection of these and other problems that must be met by a better coupling of the forces of science, technology, and society.

Let me turn now to a few thoughts on the approaches we must take to put science and technology to work to meet the vast range of challenges that face us. Just as we are recognizing that these challenges are related, so must we begin to recognize our resources and capabilities to deal with them as related and strengthen their relationship. This has been a major goal of the RANN program and it should be emphasized more throughout science and government.

Breaking Barriers

We must break down some of the separation that has existed between basic research, applied research, development, and the potential users of the knowledge and know-how research and development generates.

As I look back on my life associated with problems of science and technology in our country I think those that my friends and I were proud to be some part of were problems for which we found ways of bringing together basic research, applied research and development, and the users. The examples I recall best were the space triumph and our successes in some of the military fields. We must do the same now in some of the new emerging areas of national need.

We have to create a better flow of information, to bring the diverse forces closer together. For example, our universities and colleges which have always been our major resource for basic research should, I believe, have greater direct exposure to the problems of industry and the public sector. The motivation for this on our campuses is quite strong today.

Let me tell a little anecdote. When I first went as president to what was then Carnegie Tech and now Carnegie Mellon University, the movement was growing on campus for association more with the emerging problems of national needs. One of the first meetings I had with faculty members was with a group that wanted to start a transportation center. They had wonderful ideas. We talked at dinner and other meetings, and they expounded these ideas.

I said, "You've convinced me. We will set up the center. Which one of you is going to run it? Which one of you is going to change from your current ways?"

Of the people with the wonderful ideas, none volunteered. And I said, "Well, that's the missing link. When that happens, we will set up the center."

A year later, three of them came and said, "We are ready to move."

We set up a center and it has become quite a success. It took that, however, in our universities—not just the business of telling somebody else that they ought to solve the problem, but in fact, getting involved themselves.

Moves Toward Involvement

I think that we more and more have the necessary ingredients to move in this direction—more motivation on the part of industry and state and local government—to get together to see if more can be done to solve cooperatively each other's problems—to meld markets and public needs. The Intergovernmental Science Program associated with RANN has been active and initially successful in bringing these elements together and generating a new degree of cooperation between them. But certainly, much more needs to be done in this direction. So far we have tapped only a small portion of the huge reservoir of knowledge and creativity that resides in our academic and industrial communities in terms of how it can be applied to our national needs.

Our Federal laboratories represent another great scientific and technological resource that we could use more effectively to attack a wider spectrum of our domestic problems. We have begun to draw on them more heavily for work not directly related to their original missions, but for which they have developed excellent capabilities.

One action of the Federal Council on Science and Technology (FCST) is to enliven the Federal laboratory committee. Dr. Richard W. Roberts, Director of the Bureau of Standards, has taken the leadership and we are looking forward to great progress there. As you know, the great Atomic Energy Commission laboratories have made outstanding contributions—Oak Ridge and Argonne in the environmental field, Brookhaven in biomedical advances, and the Los Alamos Scientific Laboratory in geothermal energy and tunneling. A similar situation exists in the contributions we are receiving from NASA's research facilities and their contractors in the aerospace industry.

"Sociological Fix" Needed

It is interesting to note that some of the contributions of the aerospace industry are not just in technology transfer—in finding ways for society to make use of space hardware and its spinoffs—but in applying systems thinking to environmental and social problems. There is an important lesson here—that science must always be viewed, and accepted, in a broader context than that of a means of producing knowledge which can then be translated into technological hardware. The growing software side of science must be emphasized. And more people must be given the information that will help them realize that the ideal scientific society is first and foremost a human society in which rational thought that influences human activity and produces worthwhile change is just as important, if not more so, than the "technological fix." This broader outlook, by the way, was the essence of scientific thought long before science became so closely tied to technology. We know now that much of our success in the future will depend on the "sociological fix"—on figuring out the most beneficial human response to a problem and convicing people—even entire populations—to act accordingly.

We have seen a most important example of this taking place—although perhaps somewhat inadvertently—in our declining birthrate in this country. Of course, when this was mentioned at a scientific conference a few weeks ago, someone was quick to respond that there was a "technological fix" involved too. I will not argue that point.

I remarked earlier on making better use of the human resources we have in our universities, industry, and laboratories. We also are learning that we must make better use of existing technologies and hardware. Some of the discussions later in this symposium will emphasize this point. All across this country there are ideas, products, and potential services that could prove invaluable if matched with the right market. A major task lies ahead of us in taking these assets off the shelf and finding the right users in both the private and the public sector. Many of these ideas and products could also find a market abroad, and in the case of intermediate technologies might be more applicable to some foreign needs—particularly in the developing countries—than to our domestic markets.

Three Important Themes

It is important that this symposium, along with energy and environment, is discussing productivity. This country has long been known and admired for its productivity and efficiency, and particularly by its competitors abroad. Some years ago one of those competitors wrote of us:

> *"American efficiency is that indomitable force which neither knows nor recognizes obstacles; which with its businesslike perseverance brushes aside all obstacles; which continues at a task once started until it is finished, even if it a minor task; and without which serious constructive work is inconceivable."*

That admiring competitor, by the way, was Joseph Stalin.

Much of the responsibility for improvements necessary in energy technology, the environment, and productivity is going to fall on the shoulders of our engineers. I think that in our current situation we are rediscovering the meaning of good engineering—the art of taking science and effectively putting it to work for society. As I have said on other occasions, we are moving into an age of engineering where efficiency, reliability, and the highest standards of quality are not merely economic extras but vital necessities.

Nuclear powerplants, high speed transportation systems, and heart pacemakers are among the new items that we will be living with and depending on, that demand a new degree of dependability. Society will be counting more and more on the engineer and the industry he works with to reduce the margin for error, to translate the drive for human perfectibility into our technological systems.

Again, we can look back to some of the successes of the past, particularly in the space program. In the early days, when we calculated the necessary reliability of some of the circuits and components to get this country to turn to that great attempt to go to the moon, some of us were overwhelmingly discouraged. Yet in a short time, we got that reliability in every one of those little parts.

New Age

There are, of course, some who are concerned about the size and management of these systems today and have expressed the fear that they are becoming too large and unwieldy. A recently published book *The Coming Dark Age*, even makes the case that these systems will begin to break down in not too many years with disastrous results for the most advanced nations. Some of those very critics may be laughing as the energy crisis approaches us. But I do not agree. As this symposium indicates, along with so many of our activities today, I think we are aware of the potential problems our systems pose and able to make our course corrections well in advance of serious trouble. I think we are far more aware now than we might have been in the past that our goals are the welfare and progress of humanity; the systems really have no societal meaning in isolation.

It is true that these are interesting and puzzling times for those of us in science and technology, but we are going to meet every challenge set before us. The last quarter of the Twentieth Century will not be recorded as the prelude to a Dark Age, but as a new Age of Enlightenment—a time when man once again "saw the light" and through a new surge of creativity came to new terms with his planet and his fellow man.

NATIONAL ENERGY POLICY

Gov. John A. Love
Assistant to the President
Director, Office of Energy Policy
Washington, D. C.

It is good to see the kind of attendance that a conference on energy, the environment and productivity can adduce. If anything is necessary it is that we be better informed on the entire energy problem—now energy crisis.

As a matter of fact, I was thinking the other day, if I had known a little bit more about it, attended some meetings like this, I might not have come to take this job. Perhaps the thing to do would have been to stay home in Colorado, develop the oil shale, secede and become the King Faisal of the North American continent.

But I have felt that I have been effective. I came. There was an energy problem. It is now an energy crisis.

Seriously, when I came to Washington, I felt perhaps the first vital move was to help people realize that this was for real. It runs contrary to the American experience—where all resources, particularly energy, seem endless. To have the people of the United States realize that indeed we have shortages, and now a crisis, was the first step.

I know it has been apparent to many of you and to others but not to the nation at large, that this situation was on the way for a good many years. I remember being aware of it for the first time in any detail as governor of Colorado, attempting to promote the production of the oil shale lands. We drew the lines that indicate our domestic production is leveling off or declining, while our demands keep soaring. This builds a gap that we have traditionally on the graphs that is going to be filled by the import of crude oil and oil products ultimately almost solely, if you believe the graphs, from the Middle East.

Complex Issues

The problem was compounded, of course, by a refinery shortage and, last winter, we had the first indications of some spot shortages, primarily of heating oil—a first tremor that might have given warning of a serious heart attack if we had paid heed. And then, last summer, in the gasoline season, we had a short fall that probably nation-wide did not exceed 2 per cent but impacted in varying degrees in various parts of the country—some more seriously than others. But we had a voluntary allocation program, and we did come through without serious disruption.

In looking ahead to this winter and the demand for heating oil and the other middle distillates—diesel and jet fuel and kerosene—we forecast an increase in demand of something over 10 per cent caused in large part by curtailment of natural gas delivery and compounded by the shortage of refinery capacity. We had to look toward a solution that would have been perhaps importing 600,000 barrels a day or as high as 800,000 a day, primarily from the excess refinery capacity that existed in Europe and to some extent the Carribbean. This would have been more than we would have ever been able to import. Consequently, we anticipated a short-fall of 3.5 per cent and instituted a mandatory allocation program to attempt to put that kind of product at least into the historical pattern that existed in 1972.

Then came the Middle East war and disruption of the flow of crude oil from the Persian Gulf countries to Europe. This preceded the embargo and was disruption just by virtue of the war activities. The cutback in supply was as much as 1 to 1.5 million barrels a day. Then, the oil embargo by the Arab nations against the United States and those nations they considered unfriendly to their cause. I was a little doubtful that the Arab nations could make this work selectively and effectively against just one or a few countries—the movements of petroleum being complex and hard to keep track of. But, let me assure you, they have indeed made it effective—perhaps controlled by computers that they bought from the United States. They have followed this thing very carefully and for all practical purposes, the last ship of this kind of supply is going to be docking here this week or next.

So what does it mean? It means a short-fall of some 2-3 million barrels a day. This is measured against average, roughly 17 million barrels a day of oil used in this country last year. It means a short-fall across the board of 15, 16, maybe 17 per cent. And, it will not impact evenly in geography or end product. That is, we have a greater problem in the residual fuels than we perhaps have in others.

We are dealing now with something beyond the concern for cool or cold houses, for the lack of gasoline for discretionary driving—important as both may be. We are dealing now with potential negative impact on the economy. If you take too large a percentage of our productive machine, which historically has been fueled in large part by petroleum or petroleum products, you have the potential for serious disruption.

The programs we are devising and implementing at the Federal level are designed to curtail or eliminate uses of energy, particularly petroleum, with the least effect on our society and our economy. For example, our program in heating oil was first designed to reflect the amount the distributor and user received in 1972. That will have to be cut back by some factor, because if we were to allocate 100 per cent, we would probably sail right on through until the middle of January and then almost run out. So the shortage has to be spread out across the winter months. There seems to be no obvious or apparent difficulty with gasoline now. But, the same thing is true there. We are at present robbing refinery inventories that would be built up for next year. We will be refining less and, as a consequence, will have to cut back immediately on the use of gasoline. We will be announcing programs beyond the voluntary—many await the emergency legislation now pending in Congress.

But prior even to that, it is necessary that the people of the United States recognize the severity of this problem and join up in the kind of voluntary conservation of energy that will make it possible for us to adjust to this great challenge.

I have been encouraged in what I have seen and heard. Not everybody certainly, but a great many people are slowing down to 50. I know a great many people have set their thermostats down. I am confident that, given the challenge and being made aware of the great stakes involved, the people of the United States will respond.

Causes of the Problem

Just a word about what caused this. There understandably has been a series of questions and accusations, seeking someone to blame. I understand that. But I think perhaps it is a disservice to think that only one thing need cause our problem.

There are those who say it is nothing but a plot on the part of the oil companies. Strangely enough, I wish that were true. It would be easily solved. We would just put them all in jail and then have plenty of energy.

There are those who say that it is simply the product of the environmental movement. This is not true either. The environmental movement has delayed, to some extent, the development of some of our resources. That is true. I have a story to illustrate that. Moses leading the Jews out of Egypt came to the Red Sea. The Lord appeared and said, "Moses, I have some good news and bad news. First, the good news. I am going to part the waters of the Red Sea. I am going to let you and your people go through. I am going to bring the waters of the Red Sea back together and drown those people who are chasing you."

Moses said, "That's wonderful, Lord. What's the bad news?"

And, the Lord said, "First, you have to file an environmental impact statement."

So, delay is not always possible. But there is sufficient blame to go around. Certainly the government and the oil companies and everybody else are all entitled to their shares.

But, I think the thing you need to understand is that the root-cause has been the insatiable demand for energy, the ever-increasing rate at which we have used energy, not only in the United States but across the developed world. In that sense I have said, assessing blame, that maybe Pogo's words are applicable, when he said, "We met the enemy and he is us."

Cutbacks Imperative

In many ways we have arrived at a new world, an ending perhaps not only of endless energy but of some of the other resources, a time of adjustment and challenge. We will have to—voluntarily and in some cases mandatorily—cut back our use of energy. We will have to find solutions (and I stress the plural). There is no single, quick, easy solution.

In my opinion, the political situation in the Middle East aside, there are no real reasons why it is likely that the Arab producing nations, in their own self interest, will not increase their production to the extent necessary to take care of the pattern that existed before this current crisis.

There are domestic solutions—each involving lead time. The Alaskan pipeline, three to four years. When it comes on the line, probably not more than 6,000 barrels a day. Tremendous coal reserves. We must develop necessary investment and logistics to mine that coal and transport it—gasified or liquified—or burn it cleanly with technologically satisfactory stack scrubbers. Oil shale, at last beginning but a fairly long lead time. New refinery capacity that takes at least three years, to build a new grassroots refinery. Increase in our nuclear power. Geothermal. Solar. Ultimately, we believe, fusion, but probably not before 1990 or the year 2000.

So, I think it is true that at least for the next three to five years, we will not see any substantial increase in the domestic supply of energy. This means we will have to adjust our use and demand for energy to a fairly flat line.

American Challenge

This is going to take changes in approach, in lifestyle, perhaps in our economy, in order to make it work. They will not necessarily all be painful or for the worse. I do believe that if there is any kind of problem that Americans historically have been able to cope with, the kind of challenge presented here is that kind of problem. The technology that needs to be organized and brought to the task is particularly the kind of thing that Americans deal with well. I am sure that it can be solved.

Maybe not on the basis that we can find a new era in which we can double our use of energy every 12 or 15 years. But certainly on a basis that will provide reasonably and adequately for the kind of economy and life of society that we need.

I certainly subscribe to the goal that the President has announced—Operation Independence—that we become strategically self sufficient or have the capacity for it by 1980. I think too that we have to look at the broader-range problems farther down the line.

When you look at the Petroleum Era, if I may call it that, in the broad sweep of history, it is really a very short period of time. From its discovery in Pennsylvania in 1859 there was no major use of petroleum until about the time of World War I. Since then it has escalated at a tremendous rate. And from the forecasts I hear, it will not last, in its conventional usage, much beyond the second or third decade of the next century. So, in the sweep of history, we have a situation in which it will last about 100 years, during which we have built nations and economies on a series of machines primarily fueled and powered by petroleum products. In perhaps a Pollyanna sort of way, it may well be that a favor was done to the United States at this time by this challenge and this crisis. It is high time that we get on with the job, not only for our national and self-interest which obviously must and will come first, but in terms of the relationship between energy and development in the nations of the world. We have a great contribution to make down the line, in my opinion, to devising the technology that will make energy available in adequate quantities not only for the United States but throughout the world.

I count on all of the university and scientific communities and challenge them to bring forth the kind of solutions we must have—short, mid and long-term.

NATIONAL ENVIRONMENTAL POLICY

Gov. Russell W. Peterson
Chairman, Council on Environmental Quality
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What is quality of life? Each of us will define it somewhat differently. I view it as a measure of one's success in the pursuit of happiness. Success in the possessive satisfaction in the continuum of need. Failure to fulfill one's needs leads to the frustration and hopelessness that account for much of the anger, fear, crime, violence and alienation that plague our society. Abraham Maslow has provided an excellent analysis of this view. He described a hierarchy of needs ranging from the basic needs of food and water and shelter on up to such higher needs as self-fulfillment and self-actualization. Although each human being felt a need for all of these, his dominant goal at any one time was the unfulfilled need lowest on this list.

For example, until he had reasonably well satisfied his physiological requirements such as food and water, he had little interest in safety or esteem. But once the more basic requirements were taken care of, his drives became focused on the next goals on the list of needs. A poor person whose immediate goals are adequate food and shelter can find a good measure of happiness if he is able to work progressively towards those goals.

On the other hand, the rich person with all his basic needs granted and gratified can be miserable if he fails to obtain self-fulfillment. It is the progressive movement towards the goal that counts. Once the goal is reached, it stops being a goal. One's continued happiness then depends on his progression towards the next goal in his hierarchy of needs.

All nations of the world have people whose dominant needs fall along the spectrum: some still struggling for food and shelter and others who have obtained the highest fulfillment. In the developed nations the percentage of the very poor has been reduced to a low level. But in the other two-thirds of the world, most of the people are still struggling for the most basic of needs.

Since the dawn of the industrial revolution, the so-called developed nations have provided an ever increasing percentage of their people with an abundance of food, drink, shelter and material possessions. But as the basic needs were filled, people raised their sights to higher goals. This was especially true of young people from affluent homes who never lacked the basics of life and so started from the beginning reaching for such higher goals as esteem and fulfillment. Seeing the society around them primarily motivated by the lower or material needs, many youths find their idealism frustrated. They are demanding that we guide our future by something in addition to market signals.

Population Growth

Let us consider some other factors that will influence growth of quality of life. The greatest threat to the future well being of humanity is population growth. Among the problems of the world, it clearly stands out. Such things as aggression, nationalism and economic growth are of a second order of importance. The solution to most of the other major problems of mankind—such as malnourishment, diseases, poor housing, unemployment, pollution, depletion of resources—depends on solving the population problem.

To illustrate the impact of current population growth, let us consider future population assuming the following.

The developed nations with 1.1 billion today will continue to reduce their growth rate from today's 0.8 per cent to zero by 1985. This is a reasonable possibility. The developing nations with 2.8 billion today will continue at the current growth rate of 2½ per cent. In this case, the global population will be about 6.7 billion in the year 2000. And 35 billion in 2073, one century from now.

In other words, throughout all the centuries of history humanity has increased its number to 3.9 billion. But at the assumed rate of growth, about eight times that number or 31 billion will be added in the next century. At that time, today's developing nations would have almost 97 per cent of the world's population, compared with 71 per cent today. It should be clear from what I have just said that the population problem is a world problem. The developed nations cannot solve it.

All nations must do the job together. The developed nations can, however, play a highly important role by reaching zero population growth. They can demonstrate that the job can be done and in so doing teach by example.

Furthermore, they can help to create in the developing nations the improved economic well being that historically has been a pre-requisite to lower birth rate. A number of prestigious organizations throughout the world have pointed out that nothing from a quality of life standpoint can be gained by further growth and population. The signal is clear. Mankind has a moral imperative to limit its kind.

I believe that the world can, by an all-out effort, reach zero population growth at an equilibrium level of 7 billion. This will be difficult. But nothing short of our best effort is justified. It is not a prediction but a target. It is what could be, given a world-wide commitment and strong leadership. Any program to limit population growth must be in harmony with human dignity and individual freedom. In turn, limiting population will enhance such dignity and freedom, and help people everywhere to realize their highest potential more nearly.

Food and Quality of Life

Food is the first level in our hierarchy of needs. Yet hundreds of millions of people fail today to obtain their minimum caloric and nutritional requirements. The protein shortage is of crisis proportions and ranks well ahead of the oil crisis in many countries. The increasing affluence of protein-deficient nations and skyrocketing world trade in general are converting the world market for protein from a buyer's to a seller's market—just as with oil. Some of the most affluent nations now are competing with the poorest of the poor nations for the grain which the poor eat directly and the rich convert to meat, eight-to-one through animals. The apparent leveling off, in the world harvest of table-grade fish adds to the mounting shortage of protein. Global regulation of ocean fishing is needed urgently to insure that such fishing is not over exploited and that edible fish do not go the way of the buffalo or the blue whale.

Let us consider what productivity would be required to feed these 7 billion people who would be on our planet assuming the recommendation I made earlier for limiting the population were realized. With the current 4 billion acres under cultivation, it would require an 85 per cent increase in productivity to provide all 7 billion with today's average quality of nourishment. It would require a 300 per cent increase to provide everyone the current U.S. standard of nourishment.

Most agriculture experts believe that only marginal increases can be obtained in acres under cultivation. Even with a 7-billion people limit, the growth in mouths to feed would be the greatest in the history of the world. Between 1973 and the year 2000, the increase would be 2 billion, a 51 per cent gain in just 27 years. To feed them would be a tall order in spite of the low population level I have assumed.

Accordingly, **I recommend that the United States officially dedicate itself to working within and through the United Nations to help limit the world's population to 7 billion and to help insure that everyone in present and future generations will have a healthful and satisfying diet.** The two goals must go together, we cannot have one without the other.

Economic Growth

Next, let us consider economic growth and the quality of life. For hundreds of centuries, nearly all peoples were very poor. It was not until the industrial revolution triggered an ever-growing economic activity that appreciable numbers of people began to climb the ladder to higher and higher standards of living. The United States has led in providing the highest average level of goods and services per citizen—now approximately $5,000 a year. The United States, with less than 6 per cent of the people of the world, enjoys 33 per cent of the gross world product (GWP). It took about the last 200 years for the GWP per capita to increase ten-fold in constant dollars. The trends today indicate another ten-fold growth in just 30 to 40 years. This projected rapid growth has led to much justified concern about the long range and worldwide implications of such growth. The book, *The Limits to Growth*, by Dennis and Donnella Meadows, which stems from the work of Jay Forrester at Massachusetts Institute of Technology, has greatly intensified the worldwide debate on this subject. The book, sponsored by the Club of Rome, has been criticized on many fronts. It created a psychological shock by flashing an intellectual stone wall in front of many public and private managers and planners who are riding or steering our current political and economic juggernauts into the future.

In my opinion, however, all leaders should study *The Limits To Growth*. If all it does is make people aware of the significance of exponential growth, the certainty of limits to such growth given to finite resources and the long delay between some decisions and their ultimate impact, it will have made a great contribution. There are limits to some growth and not to others. To know which is which and how to cope with each, is a mounting assignment for leaders everywhere. Further, to make decisions today without assessing their long-range impact is foolhardy indeed.

The current energy shortage is of crisis proportions because it threatens the fulfillment of our most basic needs. A growing energy imbalance already was developing before the Arab nations' embargo on oil exports converted it to a crisis. Now it is essential that we take emergency measures such as the President has requested, to cope with this crisis. We need to respond to this problem especially by working to reduce consumption immediately. The emergency measures to waive clean air provisions in certain cases are necessary, temporarily, because more serious health hazards could be created by the impending fuel shortage. Over the long run, we need to support the President's call to get our demand and supply in balance, and to do so in tune with high-quality environmental standards.

A nation that has built an economy that uses such a disproportionate share of the world's depletable fossil fuels owes it to people everywhere to learn how to take care of its own needs in this area. We can do the job. We can stop wasting energy. We can develop a technology to use energy sources available and potentially available here at home to satisfy a reasonably growing demand. And we must and we can do this while providing at the same time a high-quality environment. The contributions of the NSF toward this end will be of tremendous importance to people today and to future generations.

Services Expand

Nearly all the present growth in the U.S. economy is in the service sector. Some say the wave of the future is service, not production. Growth in the service industry has been criticized because it does not turn out useful products. The error in this statement stems from our preconception that only material things are useful products.

Let us focus again on the conviction that the quality of life is determined by our success in progressively satisfying a continuum of needs. If this is so it seems necessary that we measure the productivity of our economic, political and social institutions by something in addition to the production of goods and in addition to GNP. So long as proportionately high numbers of our people were working to fulfill their more basic needs, the GNP was relatively pertinent. But today, when good care is taken of such needs for most of our people, additional measures are required to determine how our institutions are doing and how they are helping to fulfill our higher needs.

If the movement toward more service jobs results in more satisfied people, then its productivity could well outrank that of many goods-producing activities. If you are an owner or a manager, you do not have to produce a given product like a buggy whip, a kerosene lamp, an automobile or a barrel of oil to make a profit or to achieve the self-fulfillment of running a successful enterprise. In my opinion, varying your product line or diversifying by taking on the production of happy, healthy human beings could be highly profitable and satisfying.

An industrial manager's success in increasing productivity brings a good and growing salary with which he can thoroughly fulfill his basic needs. And, it gives him self-satisfaction, esteem and self-fulfillment. This is in sharp contrast to the lack of fulfillment of those who may be laid off by the productivity increase.

If we define productivity in terms of producing happy, healthy human beings in addition to producing desirable goods and services, the manager has the motivation to keep people on the job with good job satisfaction. He will respond to this assignment too. It is probable that the public is increasingly unhappy with leaders in nearly all fields because we have all been harping on filling their old needs when there are some new ones they want filled. This may explain why on one hand statistics show convincingly that the real affluence of U.S. citizens as measured by GNP per capita is growing rapidly and, on the other hand, most of them are convinced they are getting worse off.

Leaders need the focus on the hierarchy of needs. Find out where people are on that ladder of aspirations and then help them progressively climb to ever higher rungs. Some want only a bowl of soup and a cup of coffee while others want to compose a symphony, sculpt a statue of David, or fly like Jonathan Livingston Seagull.

Environmental Improvement

For a rapidly increasing percentage of people, living in harmony with Nature is becoming a dominant need. In light of today's knowledge, it is a non-feasance to consider economic developments without simultaneously considering their impact on the environment. Until recent years, such development has run roughshod over the environment. This has created critical problems, primarily in the developed nations, where industrial development has grown so rapidly. As the industrial nations flourish, they dig, scoop and pump ever-increasing amounts of resources, which Nature has deposited in an orderly, neat and safe fashion. Part of these resources is converted to usable products. The non-usable portion is discarded immediately and the converted portions, later, in a disorderly, untidy and frequently unsafe fashion in the air and water or on the land.

Poor people are inclined to mess up their own immediate environment and to have little impact on the more remote environment. On the other hand, affluent people manage to clean and polish their immediate environment, but in doing so have contributed to messing up more remote areas.

As the world gains more people and as more people become affluent, there are fewer and fewer remote areas in which to dig and dump. Everyone is now messing up his own nest. This fact will help to get everyone to work to clean up his common planet.

Think about the pollution pressure coming in. Even assuming we can reach the difficult goal of limiting the world's population to 7 billion, planet Earth is not going to get larger. Neither are its non-renewable resources—including its life-supporting air, water and land. But we are taking on additional passengers now in greater numbers than ever before. If we curtail population growth enough to meet the target I mentioned earlier, we will still add 2 billion—51 per cent—between now and the year 2000. That additional load is more than nine times the current U.S. population. The 18-year-olds who are finishing secondary school this year will be only 45 years old by the year 2000. What kind of a nest will they have?

More than half the people on earth today are poor. They are the ones contributing most to population growth. As I pointed out earlier, it does not appear likely that our population can be stabilized unless the poor people become appreciably more affluent. But, today's affluents are unlikely to decrease their affluence, which is currently doubling every 10 to 20 years. The pollution pressure will mount persistently even after population growth is brought under control.

We must also remember that humans, wildlife, lakes and streams have thresholds or tolerances. Exceeding them can cause catastrophic results. As a threshold is approached, just reducing percentage growth is not enough.

What can we do about the impact of economic growth on pollution of the environment? In the United States, we can further the effective program launched in 1970 with the passage of the National Environmental Policy Act and the creation of the Council on Environmental Quality and the Environmental Protection Agency. These moves constitute milestones in furthering the quality of life.

They brought consideration of environmental factors into the same league with consideration of economic factors, permanently enshrining such consideration in the decision-making process of our nation. It appears that a good way in a free-market economy to control pollution from economic activities is to bring the cost of such control to bear directly on the investment-cost-selling-price relationship of business.

The Council on Environmental Quality has estimated that the total national annualized cost —that is, operating costs plus the interest and depreciation on investments in environmental controls—will rise from $10.4 billion in 1970 to $33.3 billion in constant dollars in 1980 to meet the air and water quality standards being promulgated by the EPA. Another move being considered that would stimulate the economy to clean up its discharges is the levying of taxes. The taxes would be directly related to the quality or the quantity of pollutant discharge.

A further step that merits serious consideration is the establishment of a requirement that business be responsible for collecting, reclaiming and appropriately disposing of all of its products once they have finished their service. This would go a long way toward cleaning up the litter that plagues our countryside, recovering valuable resources, placing the cost of disposing of solid waste on the producer and stimulating the design of products whose recovery is facilitated.

World Economic Growth

Back in 1950, when the gross world product (GWP), reached its first trillion, there was little concern about pollution. Today, environmental quality is receiving considerable priority throughout most of the world. The main reason is that the prime cause of pollution, economic activity, has increased 3.5 times in just 23 years. What is of greater concern, the GWP will probably reach $12 trillion by the year 2000 and at least $42 trillion by 2050 if present trends continue. Eternal vigilance in fighting for environmental quality is a must. Future economic development must guarantee protection of the environment.

In considering the impending impact of economic growth on the environment, it is important to remember that the developing nations desperately need rapid economic development. This is necessary not only to provide higher standards of living but also to permit them to reach the socio-economic prerequisite to stabilizing population growth.

Since we in the United States have been leading the way in economic development, it is up to us to lead the way also in demonstrating how economic development can be carried out while maintaining and furthering environmental quality.

I have noted that we in this country and in other affluent nations already have fulfilled our most basic needs and now are striving to fulfill higher needs. This provides the opportunity to manage our economies in the direction of activities that will permit movement toward the higher goal.

In my opinion, many activities pertinent to achieving this objective are also what could be called resource-lean activities—activities that will use few resources and contribute little to pollution. What are some resource-lean activities that use little energy and material and that can provide satisfying and rewarding work experiences? Here are some: teaching, counselling, learning, writing, communications, citizen organization to make democracy work better, landscaping and gardening, maintenance to increase the life of capital equipment, house managing, child care, care and companionship for the aged, medical care, recreation, entertainment, arts and handicrafts, research and development.

I believe we must establish a policy that guarantees everyone a job. This policy is critical to building an economic system that helps put everyone on a route to happiness and to a higher quality of life.

Providing jobs is not only the most critical social service, it is also the most important product of an economic system. To cry out about the great importance of increasing a nation's productivity and at the same time promote idleness of a significant portion of our people is ridiculous to say the least. The term 'full-employment unemployment' should be wiped from the lexicon of economists. Emphasis on the nature of the job necessary to satisfy the unfulfilled needs of the employee should become—and I believe will become—increasingly important in the decision making of management and government.

Now let me conclude with a summary.

- **Growth in the quality of life can be unlimited.**
- **Economic well being and environmental quality are necessary and desirable elements of the quality of life.**
- **Exponential growth in population or pollution will seriously degrade the quality of life. Both must be brought to zero growth as soon as possible.**
- **Now that quality of life is determined by success in progressively fulfilling a continuum of needs, many of us in the developing nations are primarily motivated toward such things as self-fulfillment and self-actualization. Meanwhile, most of the people on earth are still struggling for the basic necessities of life.**
- **Our institutions need to alter their activities continuously to produce what is required to fulfill the changing needs of our people.**
- **Study of the growth of the quality of life makes clear the growing interdependence of all of us on planet Earth and the need for us to plan and work together.**

I propose for people everywhere a declaration of interdependence:

- **We the people of planet Earth—with the respect for the dignity of each human life, with concern for future generations, with growing appreciation of our relation to our environment, with recognition of limits to our resources, and with need for adequate food, air, water, shelter, health, protection and self-fulfillment—hereby declare our interdependence and resolve to work together in brotherhood and in harmony with our environment to enhance the quality of life everywhere.**

PRODUCTIVITY

Public Sector Productivity

RANN APPROACH TO PRODUCTIVITY RESEARCH—PUBLIC SECTOR

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All RANN programs, projects, proposals, and speeches begin with a problem statement. This is no exception. The public sector—at least as measured by purchase of goods and services—is about 20 per cent of the Gross National Product, and one of its problems is that it has been one of the more resistant sectors to social and technical innovation. There are various explanations for this condition, which will be discussed in this section. They include difficulties in measuring output and performance, high degree of labor intensity, lack of aggregated markets for public procurement, etc.

The fastest growing components of the public sector have been state and local governments. In 1960 state and local purchases of goods and services in 1972 dollars were a little over $80 billion and in 1970 were approaching $136 billion. This constitutes an annual average growth rate of about 7 per cent. State and local governments, with some distinguished exceptions, have rarely had the resources, time, and technical skills to use research and development (R&D) to enhance productivity.

Increasing productivity in the public sector implies that organizational behavior and processes have to be changed. Consequently, R&D for this sector has several peculiar characteristics. Because of these characteristics, the performers of R&D in the public sector have to behave differently than if they were conducting applied natural science or engineering research. Let me try to illustrate some of these characteristics.

First, the objective of the R&D is to provide a basis for enhanced organizational output or to better match the organizational output with social demand.

Second, the research has to be oriented to variables that policy makers can control or influence.

Third, the public sector purchases goods and delivers services in real time. To be useful, R&D must mesh with an on-going decision process. Consequently, partial information at the time of a decision is valued much more highly than complete information after a decision. In terms of research design this requirement implies the need for a sequence of partial, actionable results within a matter of months rather than a definitive result after three years or four years, as is often the case in other areas of research.

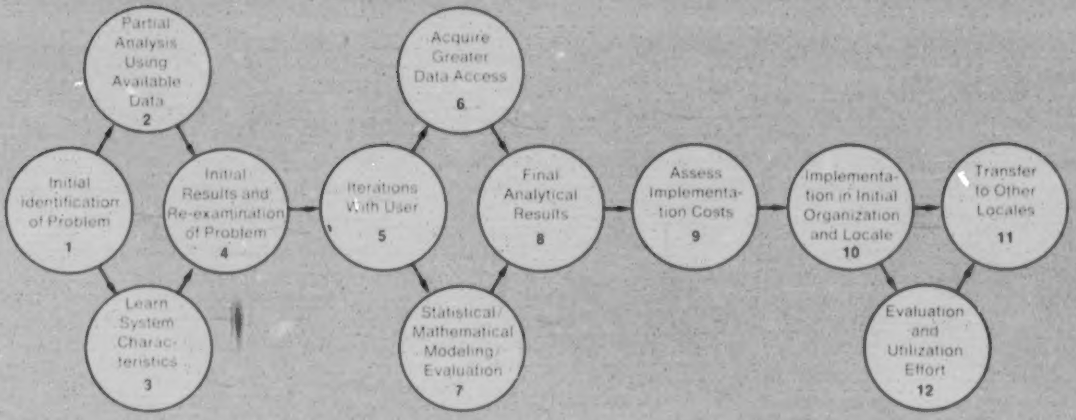
Fourth, because of the potential for social error, it is critical to accumulate and evaluate the results of on-going R&D. For example, in the fiscal year ended in June 1973, the Division of Social Systems and Human Resources obligated $3.6 million to evaluate and disseminate policy-related research in approximately 40 different municipal and human resources topics.

Research Paradigm

These general characteristics are addressed in all parts of the RANN program concerned with public sector productivity. To account for them operationally requires a certain paradigm or procedure for conducting research. The paradigm, which has eleven steps, is shown in Figure 1.

The first step is to identify the problem and define some initial specification of it that is researchable. The second step is to do some initial analysis with whatever data are available

Figure 1—Research Paradigm for Public Sector Systems


Initial Identification of Problem 1
Partial Analysis Using Available Data 2
Learn System Characteristics 3
Initial Results and Re-examination of Problem 4
Iterations With User 5
Acquire Greater Data Access 6
Statistical/ Mathematical Modeling/ Evaluation 7
Final Analytical Results 8
Assess Implementation Costs 9
Implementation in Initial Organization and Locale 10
Transfer to Other Locales 11
Evaluation and Utilization Effort 12

and to learn the system characteristics. I do not mean learn in an abstract sense. One has to ride garbage trucks, go out on police patrols, sleep in tenements and talk with service recipients to obtain an almost intuitive feeling of how a given system works and where there are critical decision points where valid research results can make a difference.

If such points can be found, one can then conduct an interim analysis that is hoped to be usable to the decision makers connected with the system. One takes this interim analysis to the decision maker and other interested parties and *asks* them whether it is interesting, useful, correct or provocative. One hopes that at least one of these adjectives applies, and the interim analysis helps in achieving greater data access. At the same time one can begin to set up some kind of evaluation device and some measures of outcome for the performance of the system. Such a device may be either a statistical model, an analytical mathematical model, an experimental design or systematic informed judgment. But some kind of evaluation device is necessary to measure outcome.

Using one's evaluation device and joining it with proper empirical data, the analyst produces a final statement, although in one sense analysis is never final. It will be continually modified by the experience of the "system."

In addition to providing analytic results, calculating the social, economic, and political costs of adopting an alternative derived from analysis has become necessary. This involves estimating what the "costs of transition" would be from current solutions to the new ones and what the organizational possibility is of implementing alternatives. For example, it is possible that one new alternative might be somewhat inferior to another on strict cost-effectiveness grounds but have greater likelihood of being implemented, because of political considerations, for example.

If the analysis is done well and provides results that are implementable, they will be diffused to the immediate user. Validated, implementable results will ideally be transferred to other locations without special research utilization efforts.

Because the market for information in the public sector is not perfect, transfer to other locations ordinarily will not take place without a special effort at research utilization and dissemination. This function in the RANN program is considered to be so important that a research utilization office has been established, as will be described in the presentation by Dr. Hersman.

Resource Availability

There is, of course, no point in having an approach to public sector research without having a budget. By the end of fiscal year 1974, RANN through the SSHR Division will have obligated approximately $35 million in the form of about 200 research projects.

In substantive content, RANN research on public sector productivity is divided into three parts:

- **Municipal Systems and Services.**
- **Human Resources and Services.**
- **Social Data and Evaluation.**

The first two parts are concerned with improving productivity through better organization, new technology, or improved management. The third part involves work on measurement and evaluation procedures that will let us know when productivity increases are really taking place. The programs in Intergovernmental Science and Research utilization are a very strong complement to this research.

Papers from two users of urban research and from two applied social researchers follow. They discuss the productivity problems of large and small urban areas as well as a major human resource problem—improving the productivity of our health care delivery.

PUBLIC SECTOR PRODUCTIVITY

Edward Hamilton
Deputy Mayor
New York City

The principal fact that makes productivity possible, I think, is the political atmosphere. This is perhaps too little remarked upon because it is so imbedded in the problem and in some ways unfashionable to talk about. In many ways, it is the beginning and the end of doing anything about public-sector productivity. There are atmospheres in which it is possible to work in the field and there are atmospheres where it is not possible to work. What I would like to do is give you some notion of two things: What kind of atmosphere produces the situation, which we have now, which seems to be particularly ripe with promise, and what sort of things we have tried to do in New York and think perhaps have some relevance elsewhere.

New Demand for Productivity

The first point I think all of us have to understand is that the world is quite different with respect to public sector productivity now than it was even five years ago. To put it in few words, public-sector productivity is now expected, where it never has been before, at least not in any politically meaningful way. We have a national electorate that not only *wants* public-sector productivity, but *expects* it, and believes it has a *right* to receive it because this electorate has made some rather important, almost radical decisions with respect to what the public sector means. It has revalued the public sector. It has made it much more important in relation to the total size and objectives of the economy than it has ever been before. It has decided essentially that a consumer economy that produces a hell of a lot of white-wall tires and beer and not very much transportation, education, housing and the other public goods is not acceptable.

The electorate demonstrated this by a quite fantastic change in the 1960s in which, among other things, 180 new Federal domestic programs were enacted. The electorate also permitted comparability between public-sector salaries and private-sector salaries. This imposed on the public sector not simply the privilege, but the obligation to produce levels of return on investment that are in some way comparable to those expected from the private sector.

Now at the same time, of course, the public sector struggled very, very heavily under the two major historical conditions that affected us in the '60s. One was a tremendous demographic change in our central cities, which changed the income base and changed by a very large factor the coefficient one would apply to each individual in terms of his need or demand for public services. Even though our central cities shrank, the workload characteristics in each of them expanded enormously. We had doubling of most service budgets and most service workload in a period of six or seven years, despite the fact that in most cases central cities were declining. The other great change was this revaluation in the public sector, which both increased the expectation, in the public mind, of what government is supposed to produce, and increased the unit price of government enormously. It did this by allowing and encouraging salaries consistent with the notion, rather new in American history, that it is important to draw as many of the best people as one can into the public sector.

Political Atmosphere

Now, what these two conditions produced was a political atmosphere that was ripe for productivity. Put more simply, a political atmosphere in which the difficulties in informing the electorate about the administrative nature of government decreased—i.e., trying to teach an ordinary citizen who has other things on his mind, for example, than what a chart-day issue is in terms of police negotiation, or any kind of allocation of public manpower. The public acquired both the patience and the desire to suffer through these problems with us and to learn something about what we are up against. But, it also learned the patience and the forebearance to live with whatever disruptions are necessary, because no change in productivity came easily. Change is bound to involve a certain amount of tension, a certain amount of friction and, from time to time, the threat of disruption of public services. The public could be said 10 years ago not to be willing on the whole to accept this. It cannot be said now, I think, at least in most urban jurisdictions.

Now what a proper political atmosphere gives you, if you are a poker player, is jacks or better to get into the game. It does not give you any answers. It simply gives you a set of conditions in which it is possible to develop answers and implement them. In our case in New York, that means essentially three things. First, gathering the human infrastructure necessary to go at problems in a systematic way. Most civil services do not grow people of the quantitative, analytic tradition, nor do civil services react very fast when change is needed. If somebody invents a computer, 30 years pass before most civil service systems can react, because the systems are not designed to produce really rapid development of new skills. As a result, one spends a lot of time just getting together the critical mass of people who can do the data generation, do the recording, do the systematic thought, do the alternative setting, do the costing and, in the end, produce a workable productivity program. In our case in New York that means 1500 people. Keep in mind that that is on a base of 320,000 employees with an operating budget of $10.5 billion a year, and a capital budget of $2.5 billion a year.

Now having assembled a group of people commensurate with the size of the task, one can do what we have tried to do in New York, which is to launch a government-wide productivity program. Understand that in many localities, the notion of a government-wide productivity program run by the mayor is not a very likely proposition, because mayors often do not have authority over large parts of their operating government. In New York, we have a highly consolidated budget that includes, for example, the entire school system, a 200,000-student university, a 19-hospital corporation and the whole welfare program. But, I think it is possible to do some productivity work in virtually any jurisdiction, on virtually any basis. Having, therefore, assembled the people, having had some experience in the analytic business and installing the systematic mode of thought in the process—usually by fairly brutal use of the budget power—one over time produces the capacity to carry out a comprehensive productivity program. Now what does that mean? In our case it revolves around four themes.

Quantifiable Results

First, consider the classic case, where output is measurable, where you have a pretty good idea of what you want to do. You can quantify what you want to do. You can generate data about both inputs and outputs, and you can come out with a simple measure of whether you are getting more return or less return on your investment. The classic case in New York is sanitation vehicle maintenance, of which some of you may know. Involved is a fleet of 1,600 trucks with an average age of 2.7 years. This is very new equipment; yet until two years ago it had an average down time of 38 per cent. Now, that is not just inconsistent with municipal fleet experience across the country; it is inconsistent with any sensible maintenance process as far as we are concerned. Therefore, a fair-sized job was done in the effort to analyze precisely what was happening. One came up with a set of problems that are not terribly unfamiliar if you are used to the business of operating the public sector from a managerial point of view. But they are not any pleasanter because they are familiar. For example, it was discovered that every truck was down about 4.2 days. Of that about 2.4 days were spent waiting for parts. The reason for the waiting was that the system had been built on an entirely rational proposition, but one that just did not have anything to do with the real world. The proposition was there ought to be a central repair shop and then a series of satellite repair shops for minor repairs. Again, perfectly rational.

The problem is that in our system a senior mechanic, as he rises in the system, has the right to bid with his seniority as to where he works. Obviously, as a mathematical proposition, he is more likely to live near a satellite minor repair shop than he is to live near the central repair shop. Therefore, he wants to work in the minor repair shop. But, like all mankind, having risen to some peak in his profession, he isn't interested in doing minor, preventive things. He wants to do interesting, major repairs. So, he does them, and he does them in a shop which is not equipped to handle them. He does them in a context of a parts inventory system that does not contemplate his doing those repairs. So, every request for a major repair part to go to a minor repair shop is treated as a very unusual event, despite the fact that it occurs all the time. The result is that the parts inventory and retrieval system is simply not geared to the realities of the world.

To correct this situation takes a certain amount of physical restructuring. But with relatively simple measures and a little negotiation at the table—some of which is not so simple—the result is what has been achieved in New York. The rate, as I stand here, is not 38 per cent.

Average down time at any particular time on any truck is 8 per cent which means a sizable increase in effective resources. Now that is the easy case and there are lots of those.

But what to do in the second case, the harder case, where output is not measurable? Who knows what a good education is? How would you measure good police work? How would you quantify these really quite judgmental, subjective kinds of services? And, incidentally, keep in mind the dangers if you get too full of yourself and decide that some partial indicator is a complete indicator. My favorite example is what would happen if someone decided that the output of the police department is represented by the arrest rate and started tying the collective bargaining system to arrests. I assure you arrests would go up. So would the city—in flames—but arrests would in fact rise. It's terribly important in this business to be as certain about your limitations as you are about your achievements. One of your limitations is that there are areas in the world that cannot be quantified. What do you do in those areas?

More Effective Deployment

You do two things. One, you develop the best set of partial indicators you can, and you can do some very interesting things. The arrest rate is an interesting indicator. It does tell you something about police work. It is not a complete indicator, but it tells you something. So is the quality of the arrest rate. What percentage of arrests is for felonies as distinguished from misdemeanors? There are lots of indicators. We have 19 of them in the police area that we think are extremely interesting. But, we do not delude ourselves that taken together they represent the total measure of police work. But, given these measures, one thing one can do is to work on the question of deployment.

Usually in our systems we find the deployment is not designed so that the profile of the work force fits the profile of the work load. We tend to have just as many foremen in the firehouses when there are no fires as when there are lots of fires. We tend to have just as many cops on the street during periods of high crime as during low crime. We tend to have just as many sanitation men working in the neighborhoods on Saturdays, when there is 40 per cent less garbage, as on Mondays when there is 40 per cent more garbage.

It is not easy to take a police force of 31,000 men and try to program it in a way that makes a more productive profile. You need to profile the work load. You need a kind of analytic talent, an approach to life, a more or less systematic programming kind of mentality to take on that problem. This is one of the reasons why it has not been done systematically in most places.

Now we have done a lot of work on deployment. If you come to New York, you will find, for example, that on Mondays there are 900 more sanitation men working than on Saturdays. You will find that the adaptive response system for fires does produce a very differential response. You will find a large number of painfully negotiated and extremely controversial, but still very effective, devices that have kept the increase in the number of Fire Department personnel to 18 per cent, despite about a doubling in the fire work load in the last five years. This is the payoff from changes primarily in the deployment and response mechanism, without incidentally increasing the response time at all, and maintaining the lowest fire mortality rate in the United States.

Paper Flow Improved

The third element of the productivity program deals with the problem of processing. This can be anything from the more mundane smaller paper flow all the way up to the most sophisticated use of computers. Obviously, it is the computers that have the glamour, but, in many ways, in terms of straight payoff, the smaller and less spectacular improvements really carry the bulk of the load. Still, computerization is the name of a big piece of the game in the business that we are in, particularly with the numbers that we deal with. We think we have made substantial inroads. Just to give an example, last year our hospital corporation, which has a budget of $800 million, had $43 million added to that budget in revenues simply from processing the 32 million pieces of paper it must process to get third-party repayments from the state and Federal government, and from the third party insured. That is $43 million more hospital care simply from processing paper better. Keep in mind that it not an easy problem. I do not recommend to you, for example, the dilemma a health insurance investigator finds himself in when he is faced with a patient who is clearly a prostitute. What does one put on the Federal government or the state government form where it says occupation. If you print what is obviously the fact you accuse her of a misdemeanor. She can be prosecuted. If, on the other hand, you do not fill in her occupation, then the paper will not contain the information necessary to get the reimbursement.

This kind of processing problem comes up again and again in government, particularly in hospital systems that have never been designed to be much interested in the financial side. Those of you who have seen the movie "Hospital," may remember the memorable character, the bitch from the Accounting Department who travels around next to stretchers being wheeled through the hospital with blood plasma dripping into veins, asking, "What is your Medicaid number?" This is a rather extreme form of the problem, but the problem is very real.

Use of New Technology

Now the final element in our program is technological. If you know anything about urban processes you know that we have a lot of new equipment, but not very many new ideas. That is, the technology that is operating in urban processes does not remind you of a country that is putting a man on the moon. It is simply not at that level of technological innovation. The reasons for this, I think, are two. One is that cities have never constituted themselves as a credible market to the private manufacturers. They have never looked like the kind of customer who could say, "If you put some of your own research and development money into this project, meet these specs, we will be there, as customers in whatever it takes, say five years, in large amounts sufficient to justify your investment."

The other reason is that the Federal government has never taken urban processes as seriously as it has taken defense, aerospace, other kinds of major national priorities. It seems to me that this has to change. What we are trying to do in New York is first to do everything we possibly can on our own hook. We have enough going on in the research area so that we can produce some things. For example, we have developed rapid water, polymerized water that goes through the fire hose with considerably less friction. This gives a choice between putting a lot more water on a fire with the same size hose, and using a smaller, lighter hose and taking one man off the fire crew.

If you know what methadone is, you may know that it was developed in our New York research programs. We think we can at last aspire to a fair number of innovations which we think we can at last aspire to because of the size of our operation, and a degree of commitment we have to that work. But in the end, the real trick is to so organize the cities and the other state and local governments that they are a credible market, that they produce pressure on the Federal government to realign research priorities, and they do represent the serious economic opportunity for the major manufacturers.

We are doing our own research, and trying to help other people organize to stimulate real centers of urban research and technology. Those are the four themes then of our productivity program—simple return on our investment where one can measure output easily; changes in deployment; improvement in processing of all kinds; and technological improvement.

Going Public

Now, to get to the final point, which is the political process. Democracy is, perhaps, most characterized by the fact that people tend to get the kind of government they deserve. Now the business, therefore, is trying to get the democracy into shape to ask for a more coherent set of public services than has heretofore been received. What we try to do in New York is to get at this problem by making our whole productivity process public.

In August we put out a productivity report for the fiscal year which contained 325 indicators of city performance. These contain a run-down of what happened last year and a set of targets for the coming fiscal year. We will, for example, deliver 5.3 per cent more refuse to the dump at X unit cost and make Y night collections—night collections being something one wants to minimize. Such targets have become a real political fact in the system. They are designed to put both the incumbent administration and its possible critics in a situation in which they can exchange views on the real world rather than on more or less rhetorical generalities. The productivity indicators are reported quarterly in a mayoral report. In it, we go over each target, state the monthly performance as against our projection and explain any deviation. This produces a particularly American mentality, of course. Americans love score cards, but the report produces a way for the interested citizen, or newspaper, or television channel or opinion maker of any kind to follow what is in fact happening with respect to performance in his locality. Understand, these procedures do not mean there is no controversy over whether the target was ambitous enough, whether the numbers are right, whether one is looking at the right thing, or whether the whole exercise is valid. But when that debate occurs, it occurs on the ground created by the fact that this system exists. It becomes necessary to take on either the numbers themselves or the process to try to comment seriously. I cannot tell you what that does for a political debate: to have to get somewhere near the real world, and either criticize or agree with a set of real data with respect to the public service one is arguing about.

We think it has been a very healthy process in New York. We find no dissent among any political party or any candidate that such a system ought to exist. I think any politician who gets into it understands that when he begins to make this kind of thing public, he does take some risk. But in the present political atmosphere, the risks are greater if he does not have some kind of reasonably valid and validatable system of measuring what he is trying to do.

Now, no improvement means anything in New York or in any unionized system until one connects it to the collective bargaining system. This is what we have done. We will not sign a contract—and have not signed a contract for three and a half years—which does not have specific measurable productivity improvement built into it. Indeed we argue that the only basis on which to consider salaries increases is productivity and some reasonable projection of inflation. Usually our projection of inflation is somewhat more reasonable than the union's projection.

We had a period when argument was made in court, for example, that productivity was not a mentionable subject at the bargaining table. There was great horror that management was putting forward demands. Nevertheless, I think the political atmosphere has made that whole set of arguments rather passe. Productivity and improvement efforts in the public sector, I think, are here to stay. It is a very encouraging trend for those of us in the business. I think there really is very little excuse for not making some major improvements in the next 10 years. I think RANN, and the kind of things RANN is trying to do, some of it incidentally in New York, is an extremely important instrument.

RESOURCE ALLOCATION IN PUBLIC SAFETY SERVICES

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During the 1960's many large cities experienced a 10 to 15 per cent annual rate of increase in demands for urban public safety services, as represented by police, fire and emergency medical services. Such demand increases, coupled with higher salaries and tighter city budgets, required city administrators to seek management alternatives other than simply adding more personnel. Systematic analysis of alternatives to improve performance and productivity have of course been carried out in the private and defense sectors. However, this has not generally been done in the municipal public service sector. Administrators in many municipal public services had simply grown accustomed to adding personnel as the sole management response to be considered. Examining the budget of these services, however, one typically finds that 90 to 95 per cent of expenditures are consumed directly by salaries, pensions and related fringe benefits. Consequently, police, fire and emergency medical services comprise some of the most labor-intensive, undercapitalized industries in the United States today.

One useful measure of the effort allocated toward seeking innovative solutions to problems is the dollar amount spent on research and development. Comparing relative expenditures in research and development, healthy growing industries in the private sector typically allocate 4 per cent of gross revenues to research and development. The Department of Defense usually obligates 10 per cent of its budget (13 per cent in the late 1960's) to research and development. In contrast, for most urban public safety services, at least through the late 1960's, it is difficult to identify as much as 0.1 per cent of total expenditures being directed toward research and development. This has changed somewhat in recent years—due to Law Enforcement Assistance Administration (LEAA) funding in the case of police, Department of Housing and Urban Development funding in the case of certain emergency services, and funding by the Departments of Transportation (DOT) and Health, Education and Welfare (HEW) in the case of emergency medical services. However, much research remains to be done, particularly in areas where no one agency (Federal or otherwise) has had interest or jurisdiction.

Our NSF-RANN research aims at developing policy-related procedures and guidelines for improving the planning and decision-making in urban public safety systems, particularly police and emergency medical services. By focusing on more than one of the traditional urban emergency services, it falls outside the jurisdiction of any one of the specialized federal agencies (such as LEAA, HEW, etc.).

The research effort is broken down into three components:

1. A comprehensive analysis of *evaluation criteria* of urban public safety services, directed toward the understanding of productivity and effectiveness of urban public safety services.
2. Development of a set of *analytical and simulation models* that should be useful as planning, research, and management tools for urban public safety systems in many cities.
3. An evaluation of the *impact of new criteria, methodologies, technologies, and organizational forms* on traditional crime-hazard rating schemes, insurance rating methods, related regulations and standards, personnel performance criteria, system operating policies, neighborhood service indicators, employees and their organizations.

If these research components are envisioned as horizontal "cuts," *police* and *emergency medical services* are the two primary vertical cuts, representing the two specific kinds of urban public safety systems on which the research is focused.

The research is strongly tied to cooperating agencies, especially in the Boston-Cambridge area, and additionally to other agencies throughout the country. It provides a close interaction of university-based research with the operational realities of police and emergency ambulance agencies. This is designed to provide early feedback from agency administrators regarding the underlying assumptions of the research and the potential utility of the research results. It is also designed to shorten the usual 5-10 year span from the inception of a research program, through the development phase, to the successful implementation of the fruits of the research in operating agencies. Current pressures for productivity improvement in the urban public sector almost demand that this time lag be cut to 2-3 years wherever possible.

Successful transfer of research results requires an understanding of the institutions in which change and innovation are proposed. To facilitate the transfer, our research project is concerned not only with developing the technical details of various management and planning tools, but also with obtaining a knowledge of the process of change within the institutions—particularly in urban police departments and emergency medical services. This work requires the integrated efforts of sociologists, contemporary historians, urban planners, police and medical professionals, operations researchers, management scientists and physicists.

An up-to-date account of these efforts can be obtained from our monthly newsletters, which are available from the Project Secretary, Room 4-209, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139.

Due to space limitations, the present paper will focus on the second research component listed above, involving the development and implementation of analytical and simulation models for planning, research and management. The paper will have three major sections. First, we will examine the quantitative tools that have been developed recently, often under the name "operations research," and place them in a larger context. This context will relate to industrial and military applications of similar tools on the one hand, and to broader organizational and institutional problems of urban public safety services on the other.

Second, we will review the methodologies contributing to the development of quantitative models of urban public safety services and outline the structure of one recently developed tool—a simulation of urban police patrol and dispatching.

Finally, we will discuss current public safety implementations of quantitatively oriented planning and management tools developed at M.I.T. The discussions will usually emphasize police applications, although significant activity is under way in the area of emergency medical services.[1] References are given to allow the interested reader to pursue details of methods or implementations that are not discussed here.

Quantitative Tools in Perspective

To place quantitative tools in the broader context of administrative and organizational problems of urban public safety systems, it is useful to review the history of their use or nonuse in public and other systems. The application of operations research and quantitative modeling to agencies with operational problems is relatively new. Most agree that operations research established its first foothold in a military environment approximately 30 years ago. Shortly after World War II it was found that many operational problems experienced in an industrial context could be addressed through the classic steps of an operations research study; define the problem, specify the objectives, define criteria relating to the objectives, specify alternatives, compare alternatives, present results, implement recommendations.

Indeed, both major applications areas of operations research—industrial and military—have been flourishing during the last 20-25 years. Many special topic areas such as inventory theory and transportation science have spun off as individual applied sciences in their own right. In fact, it is a popular notion that operations research is, by definition, a transient applied science to be utilized in substantive areas that have relatively little history or tradition of using systematic analysis. Then, the notion holds, as the knowledge and experience in a particular substantive area grow, work in that area is no longer operations research but rather management science, traffic analysis, logistics analysis or inventory control.

Implementation of operations research studies in military and industrial settings never has been entirely straightforward. But there are many documented instances of successful implementations ranging from revised military tactics during World War II, to modern inventory control systems, to system control procedures for latest generation time-shared computers.

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[1] For instance, see J. M. Hoey, *Planning for an Effective Hospital Administered Emergency Ambulance System in the City of Boston*, Report RR-01-73, Innovative Resource Planning in Urban Public Safety Systems, Laboratory of Architecture and Planning, Massachusetts Institute of Technology, Cambridge, Massachusetts, 1973.

There also are documented cases of difficult implementations and cases where there has been no implementation at all. It is concededly dangerous to generalize over thousands of operations research studies. But it would be fair to say that the majority of successful implementations occurred in instances for which either the objectives and constraints were very well-defined (e.g., maximize profit, minimize probability of system failure) or the analysts took pains to include in their study broader organizational issues. Examples of such issues are impact on personnel training, recruitment and incentives; customers' perceptions, and longer-term implications of the work in terms of how it might fundamentally change the system under study. Many unsuccessful implementations failed to consider one or more of these issues when success or failure would be determined by their degree of resolution.

A third major set of operations research applications that has emerged during the last 2-5 years is in the area of governmental service systems, including urban public safety systems. In these systems today, applications of operations research and systematic analysis are in many ways at the same point as they were in defense systems 30 years ago and in industrial systems 20-25 years ago.[2] Problems of these systems are becoming known, although their complexity has usually precluded precise formulations. The need for new methodologies has become apparent, although work in this area barely has begun. Limited implementation experience already is available, and much of this experience points to a need to consider more carefully than ever the broader organizational issues discussed above in order to provide any chance of successful implementation.[3]

Implementation Difficulties—One may question why the quantitative techniques often referred to as operations research have not had an earlier impact on governmental service systems. The answer to this is multifaceted and difficult to determine fully at this time. However, there are some obvious considerations:

1. Ill-Defined Objectives and Constraints. Objectives, performance criteria and constraints for these systems are very difficult to isolate and define. For urban public safety systems one may state as an objective the "efficient, effective and equitable distribution of quality emergency service within reasonable budget constraints." It is difficult, however, to transform such sweeping statements into performance criteria that are measured easily and into constraints whose possible violation can be determined readily. Moreover, objectives may vary among administrators, operatives and consumers in an urban public safety service.

Travel time may be offered as one possible performance criterion, but its indiscriminate use could result in the assignment of inappropriate personnel in response to a family dispute or in the assignment of inappropriate medical personnel in response to a cardiac arrest, just to save seconds of travel time. Workload equalization among personnel, if followed precisely, could result in gross inequities in the type, quality or rapidity of service delivered to various population groups. One begins to realize that a popular word in operations research, *optimization*, often bears little relevance to operational realities of governmental service systems, primarily because of the difficulties in defining objectives and constraints.

2. Lack of Productivity Measures. Since system objectives are poorly defined, so are measures of system productivity. Signals that an urban public safety system is not performing well are not nearly as apparent as a loss (rather than a profit) in a particular year for an industry or as a large cost overrun in the construction of a defense system. For instance, if one city incurs twice the per-capita crime rate of another city, this may simply mean that the citizens and police in the former city are more likely to report consistently and record accurately crimes that occur; or if a larger crime rate is a fact, it may be due in part to the number of transients who enter the city at 9 a.m. and leave at 5 p.m.

Many measures other than crime rate reflect upon police operations in a city. This fact makes impossible such statements as "City A's police department is better than City B's." Because of a lack of productivity measures, forces within an urban public safety system that would tend to favor the *status quo* often prevail. The alternative of "no change" assures that visible failure

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[2] For an overview of recent work in governmental service systems, see A. W. Drake, R. L. Keeney and P. M. Morse, *Analysis of Public Systems*, MIT Press, Cambridge, Mass., 1972.

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[3] See for example, the excellent analysis of two large scale efforts in the area of urban planning by G. D. Brewer, *Politicians, Bureaucrats and the Consultant. A Critique of Urban Problem Solving*, Basic Books, New York, 1973.

will not occur, because these systems have been working in some form for many years. But it also assures that visible progress may be difficult to achieve.

In the context of our research project, the first of the three research components examines alternative measures of performance and productivity, both system-wide and at the level of the individual officer or ambulance attendant, to provide more meaningful measures of efficiency, effectiveness and equity. The complexity of the issues involved requires that several different approaches be used. The approaches include interviewing agency personnel and consumers (performed by Prof. Gary Marx, an urban sociologist at M.I.T.), reviewing the literature from about 1900, analyzing measures and rules of thumb used currently by consulting firms and professional organizations (such as the International Association of Chiefs of Police) and reviewing how various measures have been misused so as to achieve results not desired (and possibly exactly opposite to those originally planned).

3. Internal Resistance to Innovation. These systems with their civil service orientation have tended to be insular, often fraternal, staffed with career employees whose formal education in many cases ended at the high school level. The high degree of job security frequently gives rise to an average of 20 years or more in one agency until either retirement, or (less likely) resignation or dismissal. Thus, the time constants of these systems are very long, often requiring 10 years to achieve a 50 per cent turnover in personnel. Rapid innovation is apt to be frustrated unless there are receptive personnel in key positions. Most often, implementation must be viewed as a multiyear process, making governmental services distinct from their industrial counterparts.

In our research project, Prof. Robert Fogelson (a historian in the Department of Urban Studies and Planning, M.I.T.) is analyzing the process of innovation during the last 70 years in the United States. He is focusing on the response of police personnel and their *de facto* unions to attempted innovations, both technological and organizational. This effort is aimed at providing guidance to those performing the analytical modeling regarding the projected response of police personnel and their unions to innovations that may evolve from the more narrow technical work. Fogelson's efforts should shed light on constraints that otherwise may have remained hidden until after attempted implementations, and they should suggest aspects of various innovations that police unions may find attractive (as well as unattractive).

4. Resistance to Outside Technical Assistance. Until recently, there has been no provision or motivation for agency administrators to call upon outside experts or consultants for assistance in helping analyze an operational or planning problem. In police departments, for instance, several well-known police administrators have stated that outsiders have little to contribute because they have had no on-the-beat experience. This attitude in a manufacturing firm would require all executives to start as assembly-line workers. Until the recent initiation of Federal funding programs, it has precluded successful interaction of professional problem solvers and agency administrators. Moreover, in those few circumstances in which such interaction is funded locally, the 1 or 2 per cent of the budget for outside technical assistance often receives the most careful scrutiny and subsequently the sharpest cuts, apparently neglecting the fact that 90 per cent or more of the total budget is consumed directly by employee salaries and fringe benefits. Thus, the operational problems of these agencies only recently have become known to those other than agency employees.

This situation has contributed to the delay of urban public safety services in modifying and implementing various modern technological innovations that could markedly improve performance and productivity. One example is the computer. Urban public safety systems (and many other governmental service systems) are years behind their industrial counterparts in incorporating the computer's capabilities in day-to-day planning and decision making. Prof. Kent Colton (an urban planner at M.I.T.) is continuing a multiyear survey of more than 150 police departments to determine what factors have led to delay in computer implementation and which departments have the internal capabilities to be intelligent consumers of computer services. He is also working to project the use of computers in such new application areas as resource allocation, command and control systems, and automatic vehicle monitoring systems.

5. Operational Complexity. The physics that governs the operational behavior of urban public safety systems is complex and, at this time, poorly understood. This lack is due to several circumstances. The exact times and locations of demands for services cannot be determined precisely in advance. The time required to service an incident is likewise unpredictable. There are many priority or importance levels of requests

for service. There are often many cooperating emergency response units within a region, making the number of highly interdependent status and performance variables quite large. There are needs to have point-referenced performance measures (e.g., average travel time to an emergency at a particular address) as well as area-referenced performance measures (e.g., average region-wide travel time). Each of these factors adds complexity in the operational analysis of these systems. Thus the understanding of the physical behavior of urban public safety systems is still in its embryonic stages.

The simulation model to be discussed later in this paper represents one tool for studying the physics of these systems. Others now are being developed as part of our NSF-RANN efforts.[4]

Undoubtedly, there are still other factors one might cite when discussing the difficulties of implementing changes based on methods of operations research and related types of analysis. As illustrated above, the approach used in our NSF-RANN research program includes the identification of social, political and bureaucratic factors that are at least as important as the technical results of the analysis, and the study of these with an eye toward instilling innovation as a common practice within these systems. In addition, as new quantitative tools are developed in the course of the research, we plan to document each quantitative model or procedure with an easily understood case study, selected from and with the concurrence of one of several local cooperating public safety agencies. To the maximum extent possible, we draw on the expertise of one or more of the administrators of the selected agency or agencies to obtain the following:

1. A more realistic case study, including often ill-defined legal, political and social constraints.

2. A sense of the limitations of the particular quantitative method under study.

3. The understanding and cooperation of the agency.

4. It is hoped—the commitment of the agency to implement the method at least on a trial basis.

The Relevant Quantitative Tools

Before one of the recently developed quantitative tools is detailed, the mathematical modeling methods that are most relevant are discussed briefly. These methods are presented in a new M.I.T. graduate course, "Analysis of Urban Service Systems," which has evolved from the recent NSF public systems work at the M.I.T. Operations Research Center.[5]

Geometrical Probability—One relevant tool is geometrical probability, a branch of applied probability that has seen successful application in astronomy, atomic physics, biology, crystallography, sampling theory and virology.[6] However, the techniques of geometrical probability have not been widely applied to urban public safety systems, probably because most previous applications have been in areas far removed from urban problems. Yet geometrical probability concepts are particularly relevant in examining problems involving spatial interrelationships between response units of urban public safety services and demands for their services. For instance, given the spatial distribution of police patrol units and incidents throughout the city, a police administrator can predict neighborhoods that receive inadequate coverage in anticipation of various types of emergencies that might arise, the workloads of police units in each of the areas or the likelihood that the *k*th closest unit would require more than *t* minutes to travel to the scene. Geometrical probability techniques are important in planning situations in which an administrator examines how alternative numbers and positionings of units in the field affect the performance of the system.

Generally speaking, the models developed that use geometrical probability methods have the advantage of indicating first-order interrelationships among parameters. They thereby improve intuition and provide guidance to administrators who may have to incorporate other nonquantifiable issues into their decision making. Thus, these models indicate the general nature of the effect of adding more units in a certain region, installing a high-resolution car locator system, or designating particular units as specialists in certain types of incidents. Rather than yielding precise numerical "answers" as one finds with a complex optimization model, these models typically offer a range of policy options in which the user can incorporate political and legal constraints perhaps not included in the models. Thus, the methods provide a general tool for analyzing operational questions, but they do not purport to provide precise answers to the problems.

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[4] See for example: R. C. Larson, "A Hypercube Queuing Model for Facility Location and Redistricting in Urban Emergency Services," *Journal of Computers and Operations Research*, Vol. 1, No. 1, 1974; R. C. Larson, "Illustrative Police Sector Redesign in District 4 in Boston," *Urban Analysis*, Vol. 2, No. 2, 1974; G. L. Campbell, *A Spatially Distributed Queuing Model for Police Patrol Sector Design*, Technical Report No. 75, MIT Operations Research Center, Cambridge, Mass., 1972; J. P. Jarvis, *Optimal Dispatch Policies for Urban Server Systems*, Report TR-02-73, Innovative Resource Planning in Urban Public Safety Systems, Laboratory of Architecture and Planning, Massachusetts Institute of Technology, Cambridge, Mass., 1973.

[5] See R. C. Larson, "A New MIT Graduate Course: Analysis of Urban Service Systems," *Urban Analysis*, Vol. 1, No. 1, 1972.

[6] See M. G. Kendall and P. A. P. Moran, *Geometrical Probability*, Charles Griffin and Co., London, 1963.

Multiserver Queuing Theory—A second class of relevant tools derives from multiserver queuing theory. A queuing situation evolves when a population places excessive demands on a limited-capacity service system. For instance, a city's population generates the need for ambulance service. If too much service is required in too short a time period, certain requests for ambulance service may have to wait in queue until ambulances become available to respond. An administrator would want to examine the trade-offs between the costs of additional ambulances and the delays incurred with different numbers of ambulances. This type of question can be approached from a queuing theory point of view. The important new feature in applying queuing ideas to urban public safety services is the close interrelationship between spatial positions of servers and demands, and the time sequence of arrival times and service completions. Such spatial and temporal interrelationships are relatively unexplored in queuing theory and are providing an important area for current research.

Again, queuing models are useful for obtaining first-order interrelationships among parameters applied to urban safety services. They already have provided insights about the placing of boundaries between ambulance garages, the location of facilities, the number of patrol units needed to provide an acceptable level of service, and the amount of cross-district dispatching that a system is likely to incur.[7]

Networks and Algorithms

In recent years interest has been focused on network problems and algorithms based on mathematical programming techniques. The applications of these techniques to the urban public safety systems area include problems of design of transportation, communication, distribution, and collection systems. Other applications are more unexpected; design of work schedules, work force size problems, design of hiring strategies, and optimal location of service facilities are among these.[8]

Simulation—When complex combinations of policy alternatives are being contemplated in an actual urban environment, analytical models are used first to achieve certain insights and to indicate important unresolved problems; then simulation models are used to examine the policy alternatives in detail.

Simulation of urban public safety systems presents many new problems not ordinarily faced in more usual situations. To be effective, such a simulation must be structured to reflect fully the spatial relationships inherent in the operations, as well as the sequential time nature of events common to many systems. The spatial organization of the simulation must be sufficiently general so that one can readily examine problems involving partitioning of a city into various service districts (e.g., ambulance or hospital districts, police patrol sectors), spatial distribution of response units and incidents within districts, and determination of preferable dispatching strategies.

A Simulation of Urban Police Patrol and Dispatching

As part of our NSF-RANN work we are developing a number of quantitatively oriented tools to assist decision making based on the methods outlined above. Some are just now at the point of inception, whereas others are well down the road toward implementation in operating agencies. In the following paragraphs we describe a simulation model of police patrol and dispatching that falls in the latter category. It was developed under NSF support at MIT several years ago and now is being implemented in several police departments in the United States and Canada. Continued refinement and analysis of implementation results is an important part of our NSF-RANN work.

The simulation model is constructed to allow users to replicate to a very great extent of the actual dispatch and patrol operations of most urban police departments. It provides thereby a tool to assist in answering a wide range of allocation questions. Police administrators should find simulation models valuable for the following purposes:

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[7] See for example, Drake, Keeney, and Morse, *op. cit.*, especially Chapters 7, 8, and 10.

[8] See C. Revelle, D. Marks and J. Liebman, "An Analysis of Private and Public Sector Location Models." *Management Science: Theory*, Vol. 16, 1970, pp. 692-707. Also N. B. Heller, *Proportional Rotating Schedules*. Ph.D. Dissertation, University of Pennsylvania; Philadelphia, Pa., 1969.

1. They facilitate detailed investigations of operations throughout the city (or part of the city).
2. They provide a consistent framework for estimating the value of new technologies.
3. They serve as training tools to increase awareness of the system interactions and consequences resulting from everyday policy decisions.
4. They suggest new criteria for monitoring and evaluating actual operating systems.

Earlier work by Colton[9] reporting survey results from approximately 500 police departments revealed that police view the use of computers for resource allocation as the single most important application of computers in the coming years. Simulation models and other analytical tools should play an important role in this work.

Overall Model Structure—This section will outline the structure of the model developed by the author and its use in an on-line interactive mode. The simulation works in the following way. Incidents are generated throughout the city and distributed randomly in time and space according to observed statistical patterns. Each incident has an associated priority number, the lower numbers designating the more important incidents. For instance, a Priority 1 incident would be officer-in-trouble, felony-in-progress or seriously injured person; a priority 4 incident could be open fire hydrant, lock-out or parking violation. As each incident becomes known, an attempt is made to assign (dispatch) a patrol unit to the scene of the incident. In attempting this assignment, the computer is programmed to duplicate as closely as possible the decision-making logic of an actual police dispatcher. In certain cases this assignment cannot be performed because the congestion level of the force is too high; then, the incident report (which might in actuality be a complaint ticket) joins a queue of waiting reports. The queue is depleted as patrol units become available.

The model is designed to study two general classes of administrative policies—the patrol deployment strategy, and the dispatch and reassignment policy.

The patrol deployment strategy determines the total number of patrol units, whether units are assigned to nonoverlapping sectors, which sectors constitute a geographical command and which areas are more heavily patrolled than others. The dispatch and reassignment policy specifies the set of decision rules the dispatcher follows when attempting to assign a patrol unit to a reported incident. Included in the dispatch policy are the priority structure, rules about cross-precinct dispatching, the queue discipline and so forth.

The model tabulates several important measures of operational effectiveness. These include statistics on dispatcher queue length, patrol travel times, amount of preventive patrol, workloads of individual patrol units, the amount of intersector dispatches, and others.

The simulation program is organized to reflect the spatial relationships inherent in patrol operations, as well as the sequential time nature of events which is common to all simulations. First, the spatial or geographical structure is discussed, then, the time sequence of events.

Geographical Structure—The city, of arbitrary shape, is partitioned into a set of "geographical atoms." Each atom is a polygon of arbitrary shape and size. The atoms are sufficiently small so that any probability density function can be considered uniform over the atom. Such functions depict, for instance, the positions of reported incidents. This partitioning does not restrict accuracy of results, because the atoms can be arbitrarily small.

A patrol unit's *sector* is a collection of atoms. The atoms in the collection need not be contiguous (spatially) or consecutive (in the numerical ordering of atoms). In general, each atom may belong to any number of patrol sectors, which are overlapping.

A patrol command (for instance, precinct, district, or division) is also a collection of atoms. Each sector must be fully contained within a command.

Time Sequence of Events—The simulation is an *event-paced* model. That is, once a certain set of operations associated with one event is completed, the program determines the next event that occurs and updates a simulation clock by adding, to the present time, the time until the next event. The program then proceeds with the set of operations associated with that event.

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[9] K. Colton, "Police and Computers: The Use, Acceptance and Impact of Automation." *1972 Municipal Year Book*, International City Management Association, 1972.

Once the clock reaches some maximum time (T_{max}), the simulation is terminated and summary statistics are tabulated and printed. One completed run of the simulation entails inputting data, initializing simulation status variables, executing the program for an equivalent time T_{max} and printing the summary statistics.

The details of the various dispatching algorithms or patrol deployment policies are not included here. But a brief discussion of the important parameters at each point in the simulation is provided.

The main type of event that occurs is a reported incident or a "call for police service." The times of occurrence of calls are generated as in a Poisson process with rate parameter LAMBDA (equal to the average number of calls per hour). The greater the value of LAMBDA, the more likely it is that the system will incur congestion (saturation) of resources. The location of the call is determined from historical patterns which indicate the fraction of calls that originate from each atom; given the atom of the call, its spatial location within the atom is assumed to be uniformly distributed. The priority of the call is determined from historical data which may vary by atom.

Once the position and priority of the incident are known, the program executes a DISPATCH algorithm, which attempts to assign a patrol unit to the incident. This algorithm is governed by the *dispatch policy* specified by the user. One component of the dispatch policy specifies the geographical area from which a unit may be dispatched:

> **Option 1:** Only assign a unit whose patrol sector includes the geographical atom containing the incident (a sector policy).
>
> **Option 2:** Only assign a unit whose precinct or district designation is the same as that of the incident (a precinct or district policy).
>
> **Option 3:** Only assign a unit whose division designation is the same as that of the incident (a division policy). A division consists of several precincts or districts.

The particular option on a given run usually is specified at the start of the run, although the user may choose to use the interactive feature to alter the dispatch policy during the course of a run.

Given that a patrol unit is within the correct geographical area for a particular incident, the algorithm then determines whether the unit is considered eligible for dispatch to this incident. This determination focuses on estimated travel time to the incident, the priority of the incident and the current activity of the patrol unit. In general, the user may specify a dispatch policy that allows very important incidents to preempt (interrupt) patrol units servicing incidents of lesser importance. In addition, the importance of preventive patrol may vary with each unit, thereby giving the user the capability of assuring at least some minimal level of continuous preventive patrol.

If no unit is found eligible for dispatch, the reported incident is inserted at the end of a queue of other unserviced incidents. There may be separate queues for each command and each priority level.

If at least one unit satisfies the eligibility conditions, it is selected for dispatch according to a prespecified criterion such as minimal expected travel time. The assigned unit's priority status and position are changed accordingly.

A second major type of event occurs when a patrol unit completes servicing an incident. A REASSIGNMENT algorithm then is executed that either reassigns the returning unit to an unserviced incident or returns the unit to preventive patrol. The eligibility conditions regarding priorities, travel distances, and geographical areas are necessary to specify a dispatch policy. They also constitute an integral part of the reassignment policy. In addition, it is necessary to specify how one unserviced incident is given preference over another. This part of the reassignment policy, called the *reassignment preference policy*, parallels the *queue discipline* in ordinary queuing systems.

Location Estimation—If not all available position information is used or if the unit is performing preventive patrol, the method of estimation of patrol unit position must be specified. Three options are available. One simulates the information provided by an *automatic car locator system*.[10] The other two simulate estimation guessing procedures that are commonly found today in most police operations.

Simulation Variables—The simulation program can tabulate statistics on any algebraically defined variable. The variables that have been recorded most often in the author's studies are:

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[10] See R. C. Larson, *Urban Police Patrol Analysis*, MIT Press, Cambridge, Mass., 1972, Chapter 7, for more details of simulating automatic car locator systems.

1. Total time required to service an incident, that is, travel time plus time at the scene.
2. Workload of each patrol unit, measured in total job assignments and in time spent on jobs.
3. Fraction of services preempted.
4. Amount of preventive patrol.
5. Travel time of a unit to reach the scene of the incident.
6. Dispatcher queue length.
7. Dispatcher queue wait.
8. The number of intersector dispatches.
9. The fraction of dispatcher and/or reassignment decisions for which the car position was *estimated*, rather than known exactly.
10. The fraction of dispatch decisions which were nonoptimal, in the sense that there was at least one available unit closer to the scene of the incident.
11. The extra distance traveled as the result of a nonoptimal dispatch assignment.

As will be discussed below, each variable may be tabulated at any one of several levels of aggregation.

On-Line Interactive Capabilities—Following the initial creation of the model at MIT, a number of individuals and organizations have been modifying and developing the model for various implementation purposes. Here we discuss one such effort by R. Couper, K. Vogel and J. Williamson[11] which has been devoted to implementing an easy-to-use on-line Input/Output package with the simulation. This effort has resulted in a program that is usable readily by someone without detailed knowledge of computer operation, the simulation logic, or statistics. (Several other simulation development efforts are outlined in the next section.)

The core of the Input/Output package is a sequential tree structure, which presents to the user the options available to him. If the user expresses interest in a particular option, details of use are printed out, the level of which is determined by the responses of the user. Default options are standard, so that if the user does not know what to do at a particular point, a simple carriage return yields additional helpful information. A sample Input/Output session is depicted in Table 1.

TABLE I. **Sample I/O Session**

Enter districts to be simulated (or enter "all").
15 (Italics indicate user's instructions.)
Enter districts you wish to modify.
none
Do you want to change any variables?
yes

Simulation Variables and Their Values

1. Length of simulation run = 2.00 hours
2. Number of calls per hour =

Distr.	1	2	3	4	5	6	7	11	13	14	15
	8	17	8	12	5	6	4	10	5	5	3

3. Vehicle selection method = Strict center of mass
4. Service time at scene and vehicle response speed

Priority	1	2	3	4
Serv. time (in min.)	33	33	33	33
Resp. speed (in mph)	15	12	12	10

5. Type of simulation output = City
6. More detailed information

Enter number(s) of those to be changed
1, 3, 5

1. Enter the length of the simulation in hours =

20

3. There are 3 vehicle selection procedures, they are =
   1. Modified center of mass
   2. Strict center of mass
   3. The resolution of a vehicle location system

Please enter the number of your choice =
2

5. Do you want city-wide or district simulation output?

district

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[11] R. Couper, K. Vogel and J. Williamson. *Final Report on the Computer Simulation of the Boston Police Patrol Forces.* Urban Sciences, Inc., Wellesley, Mass., 1972.

Once the initial input/output session is completed, the user has specified the following: the particular geographical data base he wishes to employ (these data are usually stored on disk), the patrol deployment policy (a standard one also is stored on disk), the dispatch procedures, the method of car location estimation, the length of the run and whether he desires to trace the simulation (and possibly interact with it) while in progress.

Following completion of the simulation, a LEVEL 1 output is printed. A sample is shown in Table II.

Table II. **Sample LEVEL 1 Output**

```
        STATISTICAL SUMMARIES—
           DISTRICT NO. 15

    The average patrol unit spent 34.21%
of its time servicing calls.
    Average response time to high-priority
calls was 6.40 minutes.
    Average response time to low-priority
calls was 7.27 minutes.
    Average travel time was 3.19 minutes.
Average total job time was 34.59 minutes.
```

This contains a small number of highly aggregated statistics describing the run: average travel time, average total response time (including queuing delay), average workloads, etc. The LEVEL 1 output contains no statistical jargon (for instance, variance or sample size) and no program variables. It is self-contained and self-explanatory. LEVEL 1 output has been found to be quite useful for introducing police planners and administrators to the capabilities of the simulation and for quickly eliminating runs with obviously poor performance characteristics.

At this point the user may request LEVEL 2 output. A sample is shown in Table III. As can be seen, this level is less aggregated and provides average values of many variables by priority level. It is expected that a sizable number of users will find the information presented in LEVEL 2 adequate for certain high-level planning and decision-making problems, such as determining overall manning levels.

Table III. **Sample LEVEL 2 Output**

```
Do you want to see LEVEL 2 statistics?
yes
    Statistical summaries—District No. 15
    An average of 34.21% of time of all units was
spent servicing calls.
    The following units were substantially below
this figure:
        Unit No.      Unit Type        %
           4           Wagon          0.00
    The following units were substantially above
this figure:
        Unit No.      Unit Type        %
           1          Sector Car      79.14
    Average times for each type of call were
as follows:
                     (Stated in Min.)
              Dispatch     Travel     Response
    Priority   Delay        Time        Time
       1        0.00        1.60        1.60
       2        5.06        3.40        8.46
       3        0.00        0.00        0.00
       4        3.72        3.55        7.27
                ----        ----        ----
                3.62        3.19        6.81
    The average travel time was 3.19 minutes
with regular spread.
    10.53% of calls incurred a queuing delay due
to car unavailability.
    0.32=aver. extra miles travel due to not dis-
patching closest car.
    Average total job time (travel time + time at
scene) by priority was:
                   1.  77.54 minutes
                   2.  37.45 minutes
                   3.   0.00 minutes
                   4.  18.05 minutes
    The average queue length for each type of
call was:
                   1.  0.00
                   2.  0.51
                   3.  0.00
                   4.  0.43
    The maximum delay in queue for each type of
call was:
                   1.   0.00 minutes
                   2.  35.39 minutes
                   3.   0.00 minutes
                   4.  33.46 minutes
```

If the user desires even more detail, he may now request portions of a LEVEL 3 output. A sample is shown in Table IV. As one can see, this

Table IV. **Sample LEVEL 3 Output**

```
Do you want to see LEVEL 3 statistics?
yes
                     District Summary
                                  Over-  Stand-
                                   all    ard    Maxi-
                                  Aver-  Devi-    mum
  Parameter                        age   ation   Value
  1. Workload (%)                 34.2   28.6    79.1
  2. Response time
     (minutes)                     6.8   10.9    39.8
  3. Travel time
     (minutes)                     3.2    2.0    10.5
  4. Extra distance (miles)        0.3    0.4     1.2
  5. Total job time
     (minutes)                    34.6   49.2   227.3
  6. Number of calls pre-
     empted for higher
     priority                        = 0 ( 0%)
  7. Number of calls
     assigned to unit on
     preventive patrol               =17 (89%)
  8. Number of calls
     assigned to unit
     assigned to sector              =17 (89%)
  9. Number of calls
     assigned to cars
     other than closest              = 7 (37%)
For which parameter do you want a further break-
down?
1
                    Workload by Priority
  Patrol
   Unit      1       2       3       4      Total
    1      47.4%   17.6%   0.0%   14.2%    79.1%
    2       0.4%   17.3%   0.0%    7.1%    24.8%
    3       0.7%   19.7%   0.0%   12.5%    32.9%
    4       0.0%    0.0%   0.0%    0.0%     0.0%
Do you want more detail for any other parameters?
yes
For which parameter do you want further break-
down?
7
By priority?
no
For which units?
all
      Calls Assigned to Unit on Preventive Patrol
    Patrol Unit     No. Calls         Per Cent
         1              6              100.0%
         2              6               85.7%
         3         [illegible]          83.3%
         4              0                0.0%
```

level presents many detailed statistics and can be of great assistance in very fine-grain planning problems—for instance, sector design. It is expected that very experienced users usually will demand LEVEL 3 output before making decisions affecting actual operating procedures in the field or at the dispatcher's position.

Regarding the other on-line capabilities, the TRACE option, which prints out the details of each call, assignment and reassignment in real time, assists new users in learning the operation of the model and in developing a good intuition for system operation. The TRACE option potentially can be used for training dispatchers in new dispatching procedures. In this mode of operation, the computer would request the user to make the dispatch or reassignment decision at the appropriate times, and the standard DISPATCH and REASSIGNMENT algorithms would be by-passed. Once the dispatcher-user settles on a particular strategy he wishes to test in detail, he can stop the TRACE, input the control parameters describing his strategy and run the model for a sufficiently long time to obtain reliable statistics.

Implementation

At the time of this writing (January 1974), the simulation model described above and several other models being developed as part of our NSF-RANN work are being implemented or are planned for implementation in the following cities: Boston; New York; Washington, D. C.; Quincy, Mass.; Newark, N. J.; Cambridge, Mass.; and Lowell, Mass.

The work with Boston, Cambridge and Quincy is being supported as part of our NSF-RANN activity. It focuses primarily on various analytical models for sector design, dispatch selections, and preventive patrol allocation. The remainder of the implementation work, supported by various other agencies, utilizes the simulation model described above and, in one case, a resource allocation algorithm,[12] both of which were developed at MIT several years ago under NSF support. Their technical details now appear in the open literature.

The following paragraphs outline a portion of this implementation activity, focusing first on the work in the greater Boston area. Much of this work utilizes the so-called hypercube queuing model,[13] which currently is being developed and extended under NSF-RANN support.

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[12] See R. C. Larson, *Urban Police Patrol Analysis* (note 10), Chapter 5.

[13] See, for example, R. C. Larson, *A Hypercube Queuing Model, op. cit.;* R. C. Larson, *Illustrative Police Redesign;* G. L. Campbell, *op. cit.;* and J. P. Jarvis, *op. cit.*

Boston—The Boston Police Department announced Sept. 18, 1973, the largest change it had ever made in its policies of patrol manpower allocation. The total number of cars on the street was increased from a daily average of 179 to 261, an increase of 46 per cent. Commissioner Robert J. diGrazia announced that the department's new "Maximum Patrol and Response Plan" was the result of a five-month study by the Police Command Staff, the Bureau of Field Services, field personnel and consultants. During July, a case study applying the hypercube queuing model to District 4 in Boston was done by the author in response to a request from the Police Command Staff. Copies were distributed to the Boston task force. The initial focus was on District 4 because that district contained nearly an entire spectrum of neighborhood characteristics to be found elsewhere in Boston. Thus, it was felt that if the plan worked in District 4, it would also work in the other Boston police districts.

Several quantitatively based objectives provided the goals of the reallocation plan:

1. Provide immediate response (i.e., no queue delay at the dispatcher's position due to patrol unit unavailabilities) for at least 95 per cent of all calls.
2. Approximately equalize workload per car.
3. Provide about 50 per cent of street time for patrol.

The District 4 Commander, Deputy Superintendent Joseph M. Jordan, reported that 93 per cent of calls were answered immediately during a trial implementation in District 4, using numbers of patrol units derived from queuing analysis.

Workloads were distributed very unevenly prior to implementation of the new plan. For instance, cars in District 7 (East Boston) were answering calls for about three hours during the day, five hours at night and two hours in the early morning shift. However, cars in District 11 (Dorchester) were answering calls for more than six hours during the day, virtually all of the time during the night shift, and more than seven hours during the early morning shift.

Furthermore, District 11 cars were often unable to respond to all of the calls during the night shift. The new plan attempts to give at least four hours to each car in each shift for preventive patrol activities. It significantly reduces such marked workload inequities.

Examining the computational results of the case study, the Task Force felt additional workload and travel time inequities due to geographical factors could be significantly reduced by formalizing a procedure for *inter-district* dispatching. Thus, a sector which may have been "outlying" in one district now may assume a new central role if its patrol unit is dispatched to calls in an adjacent district. The converse is true for units in the adjacent district.

The extra manpower required to implement the new Boston allocation policy was drawn from sworn police personnel performing clerical functions. The Task Force found that many clerical functions were unnecessary or could be handled by other agencies. Many non-vital clerical functions were eliminated, including such functions as duplicating at the district level records available at headquarters. New organizations were drawn for district personnel and new procedures developed to speed the remaining paper work, thereby making policemen who previously performed clerical functions available for street duty.

Cambridge and Quincy, Massachusetts—Use of the model by the Cambridge and Quincy Police Departments still is at a more preliminary stage. The directors of planning and research of both departments are now collecting the data required to operate the model. Both plan to perform the sector-redesign iterations themselves, using the computer programs developed at MIT.

The Cambridge sector plan has not been redesigned for more than 20 years, and there is evidence of marked inequities in patrol workloads. An officer assigned to the most centrally located sector has recently complained to planning and research staff about the operation of his police car radio. He was asked, "What is the matter? Doesn't it work?" He responded, "Yes, it works—that's the problem. Every time I'm free, I'm being sent to someplace else in Cambridge on another assignment." Naturally, the Cambridge Director of Police Planning and Research hopes to reduce this workload burden by exploring different sector design options with the aid of the model.

The Quincy Police Department is performing a broad-based operational analysis under a grant for innovative planning, supported by the Massachusetts Governor's Public Safety Committee. (This committee is the state planning agency in Massachusetts for the Law Enforcement Assistance Administration of the U.S. Department of Justice.) Part of this activity requires use of analytical and simulation models of police activity to improve planning and day-to-day decision making. The City of Quincy, situated on Quincy Bay, has many natural and man-made barriers to travel, thereby limiting the number of feasible alternative sector designs. The Director of Planning and Research is therefore particularly interested in learning the magnitudes of the effects on performance discussed here in a Boston context.

Both the Cambridge and Quincy implementation experiences will be documented as reports of our NSF-RANN project.

Washington, D. C.—An off-line version of the simulation model is being created and implemented for the Washington, D. C., Metropolitan Police Department under the technical guidance of Mathematica, Inc. and with the support of the Law Enforcement Assistance Administration.[14] Here the city's geographical structure is modeled as a set of discrete points, rather than polygons, each point corresponding to one city (surveyor) block. For Washington, D. C. this represents approximately 4,000 points, or sufficiently fine-grain detail to make the model useful for sector redesigns for the 138 scout cars distributed throughout the city. The selection of a point geography was based on detailed block-level statistics available for Washington, D. C., and on the fact that an off-line model need not produce rapid turnaround times (in the same sense as an on-line real time model). This effort began in January 1972, and is reported in periodical publications of Mathematica, Inc. and the Washington, D. C. Metropolitan Police Department.

New York—The New York City Police Department in August 1972 contracted with the New York City-Rand Institute to adopt the on-line simulation and a resource allocation algorithm to the special requirements of New York City and to implement these tools for analysis of the entire patrol force (distributed throughout 75 precincts in over 700 regular radio-dispatchable patrol cars, plus special-assignment cars and radio-dispatchable foot patrolmen). The Department eventually hopes to provide each precinct commander with a readily understandable set of on-line decision tools, with easy terminal access from each of the 75 precinct station houses. Thus, it is hoped that these tools will be used for short term decentralized decision making, as well as for longer term centralized resource allocation, and planning and research. As of the present writing, this project still is in progress, and draft reports are available from the New York City-Rand Institute.

National Research Council of Canada—During the last two years, F. R. Lipsett and J. Arnold of the Radio and Electrical Engineering Division of the National Research Council of Canada have reprogrammed the version of the simulation model detailed in Larson (1969) to adapt the programs to their computing system. Their work is currently in progress, aimed at determining the potential usefulness of simulations to both small and large police forces. They have successfully simulated a cooperating police force near Ottawa (Gloucester Township) which operates with five sectors and five patrol cars over a 125 square mile region.[15] Their current work, now at the data collection stage, is with the Ottawa Police Department. Documentation should be available early in 1975.

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[14] See H. F. Miller and B. A. Knoppers, "A Computer Simulation of Police Dispatching and Patrol Functions." Paper presented at the 1972 International Symposium on Criminal Justice, Information and Statistics Systems, New Orleans, La., 1972.

[15] See F. R. Lipsett and J. G. Arnold. *Simulation and Analysis of the Patrol Operations of a Semi-Rural Police Force.* Document of the Radio and Electrical Engineering Division, National Research Council, Ottawa, Ontario, 1973.

TELECOMMUNICATIONS IN HEALTH CARE DELIVERY

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Although the title of this is "Telecommunications in Health Care Delivery," it would be better stated as "Problems and Possible Solutions for Health Care Delivery." I would like to share with you my views on some of the problems facing our health care system and to review a telecommunications program under way at the University of Miami School of Medicine that attempts to come to grips with the major criticisms of our existing system.

Our research program, which will be carried out in conjunction with the Department of Hospitals of Dade County, Fla., and Westinghouse Health Systems Division, is supported by a $900,000 grant from the NSF plus more than $250,000 in cost-sharing contributions by the three principal parties. The program will develop and evaluate a new telecommunications system for health-care delivery. It is intended to upgrade the quality of medical care in a prison environment. The system provides for *the utilization* of information processing technology for patient history taking and *the application* of video telemetry to provide readily accessible supervision, consultation and continuing education for the nurse-practitioner. It involves the use of nurse-practitioners for the provision of primary health care services. While none of the components of the system would be considered new or unique, the integration of these components into a single system has not been done or evaluated before.

New Demands

As you are aware, over the past decade we witnessed a growing demand on our medical resources. Despite the significant improvements in the basic sciences and public health areas, the public has been increasingly aware of the deficiencies of some aspects of the present system. Inaccessibility, lack of continuity, uncertainty about quality and rising costs have characterized the public's frustration in attempting to achieve even the simplest measure of health maintenance. We have been unable to provide every citizen who needs medical care, *comprehensive care—when* he needs it, *where* he needs it, at a *reasonable cost*, and with some measure of assurance of *continuity of quality*.

It is clear that any attempt to change the existing system (or, as some have stated, non-system) must be done critically and with a firm commitment to evaluate whatever is done. Despite the feeling that changes need to be made rapidly, it is clear that solutions cannot come "overnight." While *tradition* cannot justify maintaining the inequities of the present situation, a new idea cannot simply be equated with a proven solution. It has to be evaluated. Any new system has to be based on a clear understanding of what the problems are. What are they? Some of the major problems are distribution of physicians, lack of continuing education, defining and providing quality health care, inefficient task identification, the attitude of universities and rising costs.

Maldistribution of Talent

Many have stated that a *prime* reason for the inability to get medical care *is* a shortage of doctors. A more critical analysis would indicate that instead of our having a doctor shortage, we simply have a maldistribution of health care professionals. Maldistribution is a fancy way of saying that we simply have too many doctors in some areas and not enough in others. I suggest that we might possibly have enough health professionals if there were some way to spread them around a little more equitably.

Studies of the concentration of physicians by geographical area of the country show that proportionately three times as many doctors are in highly populated areas as are in lesser populated areas. Thus, *rural areas* are medically isolated because of *geographic constraints.* However, *urban areas* are not immune to this maldistribution problem either. The nursing home population, the ghettos, the migrant worker areas and the prisons are subjected to medical isolation as a result of social, economic and cultural constraints.

Compounding all these issues is the growth of specialized medicine. Practically everybody these days is a specialist. There are many reasons for this:

1. The vast amount of medical knowledge makes it difficult to encompass anything but a well defined area.
2. The specialty boards have shortened the time it takes to achieve specialty certification.
3. As a result of the emergence of professional standard review organizations that may define what type of patient or illness a doctor can care for, the growth of specialization will be fertilized.

But whatever the factors are, it is clear that specialization necessarily breeds concentration of health manpower and technology (i.e., maldistribution).

A number of solutions have been advanced. However, I do not feel they really come to grips with this problem. Interest is growing in the development of a national health insurance program. Now, this may help eliminate some of the economic barriers to more equitable health care. But it will do nothing for the social and geographical barriers.

One of the more popular ideas that has been proposed to effect a change in the maldistribution problem is the recruiting of medical professionals from the medically deprived areas. This idea would have the trained professionals return to the areas under something of a bootstrap concept. Although it is too soon to be conclusive, very few appear to be returning.

For those who have concluded that we have a doctor shortage rather than a distribution problem, the solutions proposed have been to increase the number of doctors that we graduate. As I hope has been made clear, this will probably tend to further the maldistribution and thus compromise accessibility. There must evolve new distribution systems that significantly extend the capacity of individual physicians geographically.

Continuing Education

The next problem is something of a classical challenge. It concerns the absence of any effective continuing education program for practicing physicians. It should be obvious that improvement in the medical education delivery system must be a prerequisite for any effective improvement in the health-care delivery system. Yet, in point of fact, the medical education system is open to criticism on all the bases as that directed at the health care system: maldistribution, lack of continuity and no standard of quality. Once the newly graduated medical student completes his internship and residency training, he emerges into practice and a "catch-as-catch-can" method of keeping abreast of new developments in his field. In addition, an inherent discrepancy exists between the type of health care to which the medical student and resident is exposed in our teaching hospitals and the day-to-day health care needs of the community. In many cases, medical schools and their affiliated hospitals and clinical operations have become referral centers for the most severely ill, those with rare diseases or those requiring crisis type of therapeutics. These circumstances give the developing young physician too specialized training and a rather unrealistic view of the actual day-to-day health needs of society.

More often than not, the patient's illness is not as specialized as the expertise of the physician caring for him. As an example, the patient who has a heart problem and diabetes will be cared for adequately by the cardiologist for his cardiac problem, but will probably also need to be sent by his cardiologist to an endocrinologist to handle his diabetes. This becomes group practice by default rather than design. It is a paradox that 90 per cent or more of the physicians get the bulk of their practical experience with less than 5 per cent of the patient population that actually requires a physician's care. The inappropriateness of this system is further magnified by the fact that the medical educator has become a specialist himself. As a result, his ability to provide a broad-based educational program is hampered.

Quality Definition

The next problem we face is critical too. This is the problem of defining and then providing "quality health care." To the patient, quality is defined in terms of having a comfortable and relatively quiet room or a warm bed pan. Quality to the patient is a nurse who responds quickly to a call or a doctor who has a pleasant bedside manner. The physician's peer review board, however, tends to view the quality of a doctor's care in terms of whether or not he has followed the appropriate diagnostic and therapeutic approach, whether he has under or overutilized the laboratory or X-ray facilities, whether he shows evidence of having kept abreast of the latest developments, and whether he has taken post-graduate courses.

It is not difficult to see how the *good doctor* from the patient's standpoint might not meet the quality standards established by the physicians' colleagues. It is therefore important to recognize that we must at all times know from what frame of reference we are evaluating or measuring quality—the patient's or the physician's.

Also, while the measuring ruler is not difficult to define, it must be understood that it is a relative measure requiring constant change determined by the advances in research. Today's quality health care may be substandard tomorrow. In addition, it should be apparent that in this concern over quality care, accessibility does not equate with quality. While most would agree that providing a physician to a patient who previously did not have one improves the health care system, this may not be a logical cause-and-effect relationship. A well-meaning physician who has not kept abreast may do more harm than good. This premise also holds true for our concept of *continuity of care* as a critical part of quality of care. Having to see a different physician each time you are ill, each of whom may be unfamiliar with your previous condition, would be considered poor continuity of care, and therefore poor quality of care. However, seeing the same physician each time you are ill, a physician who is unable to diagnose the condition you have because he has not kept abreast of new developments, may provide adequate continuity but *not* effective quality of care.

Inefficient Task Identification

The next problem is actually several different problems rolled into one. We call it inefficient task identification. I speak of the job of defining exactly what it is that doctors and only doctors should do in delivering medical care, and which of the doctor's tasks can be performed capably and safely by others. Many of my colleagues in medicine would tend to answer the above question by saying that *all* medical treatment, regardless how minor, is the jurisdiction of the physician alone. I am constantly reminded of a remark by one of my professors in medical school—that most of our patients *get better despite what we do to them.*

There is no doubt that many common ambulatory problems can be handled by a nurse or a paramedic as well and as expeditiously as by a physician. The physician spends too much time recording data (information) from the patient—a function that can be handled either by a nurse or automatically by machine. He does not have enough time to analyze and synthesize the data. The latter is what he *must do and has been trained to do.* It is quite obvious, however, that the introduction of paramedics, nurse-practitioners, computer technology or any combination of them will be an emotional as well as a professional issue not only for the physician, but clearly also for the patient. I am sure that most readers would prefer to have a physician record their history rather than some machine, even if I could prove that the machine could do it more efficiently and accurately. Thus, we must combine much patient and physician education with the appropriate amount of understanding and willingness to try new methods. For it is imperative that we provide a means of extending the physician's service capacity in terms of the number of patients he can serve. It must be made clear that new technology and nurse practitioners *are not* substitutes for the physician—they are expanders of *his capabilities.*

Attitude Problem

Problem No. 5 concerns itself with the attitude on the part of the universities toward the inadequacies of our existing system. The response has been predictably polarized, either reaction or reactionary.

The reaction is generated in part by the realization that the advances in the biological sciences have not been proportionately translated into an effective delivery system. This reaction has taken the form of *over-commitment* in the area of health care delivery—characterized best as an attitude of *service without science.* Departments of Community Medicine have sprung up everywhere and the "disciplines" of family medicine, primary care physicians and nurse-practitioners have been advertised as the panacea of our present situation. To date we have no overwhelming evidence to indicate their efficiency and quality. This is not to say they will not provide solutions—they may, but before *we* overcommit ourselves, we had best direct more effort in the evaluation phase. New ideas must stand the test of critical analysis.

The reactionary contingent is comprised of those educators and administrators who feel that the university has little responsibility to help alleviate the present health care crisis. Part of this response is a result of the natural reluctance to change, since it is apparent that the system that is needed will require adjustment and change of focus. Justification for this "armchair" approach is based on the premise that increased commitment to provide daily services will erode the two basic responsibilities of the university—teaching and research. This group seems to advocate *science without service*. What is forgotten is the fact that patient care is the backbone that supports and directs that teaching and research. It is the responsibility of the university to develop the models to be tested and the quality standards to be applied for new health systems. This is to be done in a framework that makes the student as well as faculty cognizant of the fact that research and critical questioning can occur at the bedside as well as in the laboratory.

Costs Rising

The final problem needs little explanation. It is the problem of soaring costs. Both patient and physician agree that our existing system is overpriced, but little has been done to improve the situation. Once again we have too quickly grabbed on to so called "guaranteed solutions," without any definitive data that demonstrates cost saving.

A tougher issue to address ourselves to is not what dollar value do we apply to the provision of care, but what value will we accept for the provision of quality care. A new health system may provide the best quality care, but at two to three times the present costs. Another system, that costs less than the one we have now, may not provide as good quality of care. Which do we choose? The *best care* may have to be compromised for *optimum care*. And whatever system is developed it is well to recognize that total costs—not cost per unit of care—may actually increase. If a new system improves accessibility to medical care, a large group of people who now receive little medical care will find that this will cause a rise in their health care expenditures.

Most certainly if we can gain a better understanding of these problems facing our health care system *today*, then we stand to make a significant impact on medical care for all areas of society with the system we develop *tomorrow*. This is exactly what we are trying to achieve at the University of Miami. From a recognition of the problems we have just reviewed have come a lot of ideas that need to be evaluated, and have generated the health system that I promised I would describe to you.

Project Described

The project is called "An Evaluation of the Impact of Communications Technology and Improved Medical Protocol on Health Care Delivery in Penal Institutions." Our program began in July and is therefore too embryonic for any meaningful results to be available now. It will run for 27 months and is being implemented in the Dade County Penal System. Involved in the study are three prison facilities shown in Figure 1—the county jail, a minimum security stockade and a women's detention center. The three are to be linked by various television modes to the main University Teaching Hospital, Jackson Memorial Hospital. We chose inmates in a prison, not only because we were fairly confident about getting our patients to return for follow-up visits, but because the penal institution represents a good cross section of the health needs of society. And as has been unfortunately demonstrated by riots such as those that occurred at Attica, the prison community happens to be one of those medical islands that I mentioned earlier.

This project has a dual purpose: both service *and* science. The service objective is to upgrade the quality and continuity of health care in prisons. The science objective is to evaluate and compare the medical and cost effectiveness of different communications methods as an adjunct to a distributed health care delivery system. Both of these goals will be approached utilizing the two phase experimental protocol, shown in Figure 2.

The first phase of the program consists of upgrading the existing prison health care delivery system, using new and innovative health care delivery techniques; but excluding video communications, usually referred to as "telemedicine." This "Baseline System" will be operated for six months following its initial implementation on January 1, 1974. During this time, all of its operational characteristics, which I will enumerate later, will be documented. Then, on July 1, 1974, the video communication links will become operational between the various sites. For one year, half of the patients will be treated as they were under the Baseline System and half will be treated using the Telemedicine System, and the operational characteristics of both systems will be documented. At the end of this period, the characteristics of all four systems (the Existing System, the Baseline System, the Telemedicine System, and the Baseline System Concurrent with Telemedicine) will be compared and evaluated.

Let us now look at each of these systems and see what it includes. The Existing System is one in which each prison has its own health clinic

Figure 1—**Prisoner Health Care via Telemedicine**

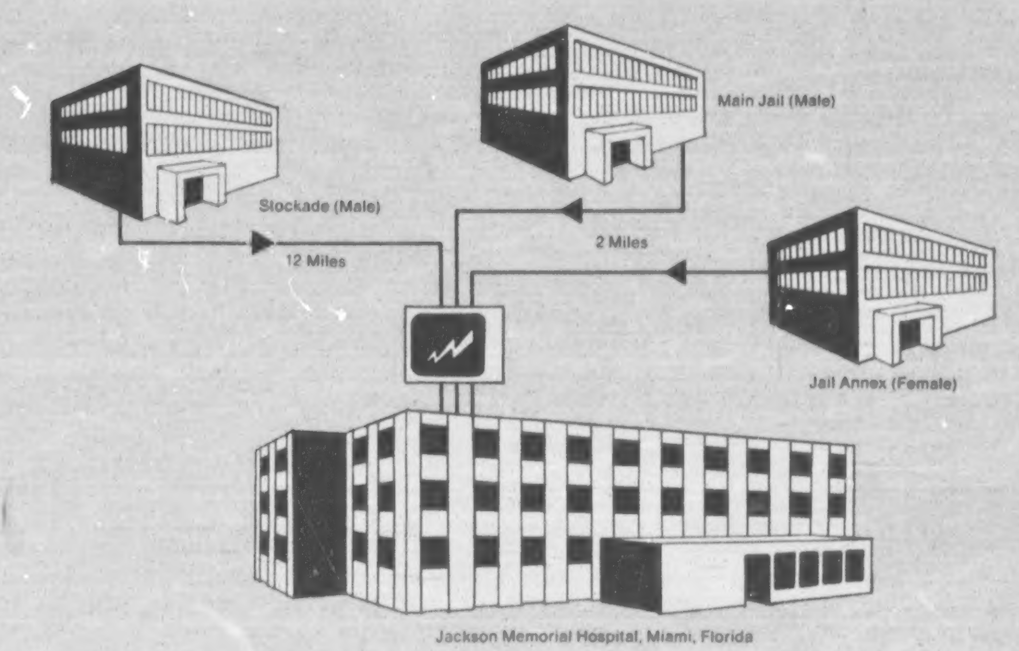
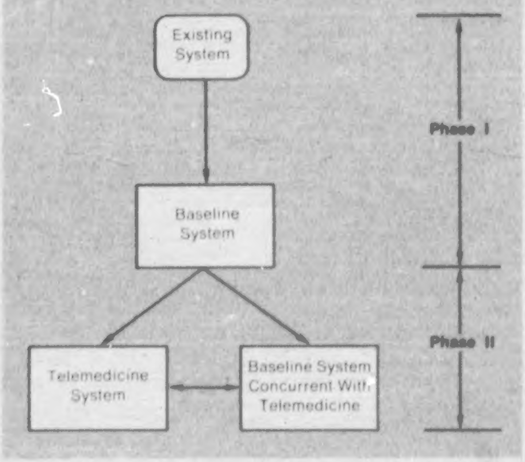

Main Jail (Male)
Stockade (Male)
2 Miles
12 Miles
Jail Annex (Female)
Jackson Memorial Hospital, Miami, Florida

Figure 2—**Experimental Setting**


Existing System
Phase I
Baseline System
Phase II
Telemedicine System
Baseline System Concurrent With Telemedicine

staffed by registered nurses, licensed practical nurses, aides, etc. They are supported by physicians from Jackson Memorial Hospital, who go to the jail clinics several hours each day. In addition, patients can be sent to Jackson Memorial Hospital for treatment beyond the scope of that available at the jails (specialty consultation, inpatient care, extensive diagnostic procedures, etc.) The existing system works reasonably well, and appears to provide acceptable quality care at a not unrealistic cost. Part of the early portion of the experiment, prior to the implementation of the Baseline System, will be a documentation and evaluation of how good that care really is and how much it actually costs.

Baseline System

This existing system will be modified in several ways to upgrade it to the Baseline System. The first and most important change will be the introduction of nurse practitioners. During the first six months of the project, registered nurses with experience in the jail clinics will undergo an intensive, 40-hour-a-week training program to prepare them as primary care nurse practitioners. As part of the Baseline System, they will then assume the direct responsibility for the medical care of the patients, with the assistance and consultation of the physicians. To the extent of her ability, the nurse-practitioners will be encouraged to assume those roles that will best extend the physician's effectiveness. I hasten to add that this program is entirely voluntary on the part of the patients. Under both the Baseline and Concurrent systems, physicians will still be available at all the jail clinics. Thus, should any prisoner so request, he will be treated by a physician at the jail, regardless of his need.

In addition to the nurse practitioners, the system changes will include the use of medical protocols; that is, physician-prepared material to assist the nurse practitioner in the diagnostic and therapeutic approach to a patient's problem. Other modifications will include the introduction of problem-oriented medical records (including patient encounter forms), automated medical history takers and the improved availability of telephone consultations with specialists at Jackson Memorial Hospital. In summary, the Baseline System to be compared with the Existing System prior to the use of any sophisticated communications technology will have the following improvements.

- **Nurse practitioners.**
- **Medical protocol.**
- **Problem-oriented medical records.**
- **Automated medical histories.**
- **Telephone consultation service.**

Throughout this phase, the quality, availability, costs and effectiveness of the medical care provided by the nurse practitioner, as well as the attitudes of both the users and the providers will be documented, and then compared with that of the physician under the Existing System. Thus, Phase I will tell us quantitatively and qualitatively how well the new health care delivery system works, when all the changes except video communications technology have been introduced. The second phase will tell us what additional improvements various types of "telemedicine" can bring to the system.

Telemedicine

Telemedicine can be generally defined as any system that permits a doctor to provide medical care at a distance or, more specifically, one that substitutes an *electronic* presence of the physician for his *physical* presence. Phase II of the project involves adding various video communication links to the Baseline System. The patient population of each jail will be randomly partitioned, some being treated via the Telemedicine System and others as they were under the Baseline, Phase I system. The only difference in the treatment of the patients under the two systems will occur when the nurse practitioner decides that assistance or consultation is needed in the treatment of a particular patient. Under the Baseline System, the nurse may refer the patient to the physician visiting the jail, telephone a physician at the hospital or send the patient to the hospital. Under the Telemedicine System, the nurse may *not* refer the patient to the physician visiting the jail unless there is an emergency requiring the immediate aid of an on-line physician. However, the nurse can send the patient to the hospital or arrange for a physician at the hospital to consult with the nurse and the patient via the video communications system. These video links will allow a primary care physician or specialist at the hospital to see, examine and talk to the patient. The examination may include listening to the patient's heart and lungs with the use of an electronic stethoscope and the interpretation of electrocardiograms or even X-rays.

Throughout the entire year of Phase II of the project, the Telemedicine System will be evaluated to determine its effectiveness in providing the nurse practitioner with supervision, consultation, quality control, and continuing education. In addition, we will compare the health care delivered to the patients under the different systems. Most importantly, we will study its acceptance by both the patients and the health-care providers as a useful communicating tool to provide health care. Thus, the entire project will compare the nurse practitioner-patient health care system with the traditional doctor-patient system, as well as determine the effectiveness of the communications technology.

Furthermore, the project will do more than look at one type of video communications. In addition to interactive video links, the systems linking the various jails to the hospitals will include voice channels, electronic stethoscopes, remote electrocardiogram channels, and even facsimile transmitters for transmission of written or graphical material. Thus, we will be installing not just a TV camera, but an integrated system of audio, video, and data communications planned specifically for medical applications and designed for use by health care personnel. Additionally, two different video systems will be installed at each of the three jail clinics as follows:

Main Jail—Live video, black and white.

Stockade—Slow-scan video, black and white.

Women's Detention Center—Live video, black and white; slow-scan, color.

Slow-scan video is a method of sending single television pictures over ordinary phone lines, taking one to two minutes to send a picture. Treating different segments of the patient population through different modes of telemedicine, will make it possible to evaluate the relative medical and cost effectiveness of each mode. This would assist other potential users of telemedicine in determining the most effective system for their needs.

Evaluation

I have discussed evaluation a great deal, and with good reason. The majority of the funds in our project will be spent on evaluation, not on hardware, installation or operations. With that in mind, it is only appropriate to describe some of the major evaluations that will be performed. There will be five major areas. These include quality of care, cost, education, acceptance, and communicating utility.

Quality of care is the single most important evaluation, and one that will be continuously performed. One of the ground rules for this type of project is that nothing must be done that will in any way jeopardize the health care delivered to the patients. Quality will be evaluated by monitoring the medical effectiveness of the program continuously via periodic reviews of the patients' medical records. A medical care review committee will examine a random sample of all medical records and determine whether the care was acceptable in its opinion. In addition, the records of all of the patients who have had any of a selected set of "indicator" illnesses will be reviewed and the treatment compared against previously established medical protocols. Further quality of care evaluations will include the following things:

1. Promptness of care—the interval between the time a patient decides he needs care and the time he receives it.

2. Physician continuity—how often, when a physician wants to follow up a particular patient himself, he can do so.

3. Patient continuity—how often patients return for scheduled follow-up visits.

The basic purpose of the cost analyses will be to develop a cost model that will allow the determination of more than just the overall operating costs of each of the systems. They will point toward determination of the cost of treating a single episode of the various diagnoses encountered, using each of the different systems, as well as the different modes of telemedicine. It will thus be possible to determine which system would be most effective in treating the entire patient population. If the results of cost and quality of care analyses were applied to another population with differing morbidity rates, they would allow the determination of the medical and cost effectiveness of differing systems.

In addition to these two extensive quantitative analyses, three less vigorous analyses will be made.

The educational effect of the telemedicine systems will be assessed by two measurements: first, monitoring of the frequency of use of the video by the nurse practitioners to consult with the physicians and, second, comparison of the scores of the providers on medical knowledge quizzes given at various times throughout the project.

The attitudes of patients, nurses, nurse practitioners, and physicians using the system will be analyzed by a series of custom-developed attitude surveys, administered throughout the project.

Finally, an analysis will be made of the communicating utility of the various users of the telemedicine system. This is a new analysis developed specifically for this project. The various users and combinations of users of the telemedicine system will be evaluated in terms of the medical effectiveness and efficiency of their consultations. Randomly selected video consultations will be recorded, and their content will be analyzed. We will then attempt to relate the types of communications with how well the telemedicine system is used.

Conclusion

This program is a multidisciplinary effort requiring the combined efforts and resources of the community and the University. An interdisciplinary team will approach the problem. It will include not only nurses and physicians, but biomedical engineers, system analysts, management scientists, sociologists, economists, evaluators and, most important of all, the patients.

If the evaluation indicates a positive result, we hope the system will have applicability not only to patients imprisoned behind bars but also to those imprisoned by other circumstances. Examples would be migrant workers, imprisoned by the nature of their socio-economic status; the nursing home population, imprisoned by their age; residents of rural communities, imprisoned by their location, or the people of underdeveloped countries, imprisoned by the infancy of their society's growth.

The true measure of the performance of this system will be whether it effects an improvement in the health of the people it serves.

A CITY-INDUSTRY EXPERIMENT IN TECHNOLOGY TRANSFER

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In this presentation we hope to give you an idea about how a city and an aerospace company have joined together as partners to conduct an experiment in technology transfer in Tacoma, Washington. We will discuss how we got together, what our motives for involvement were, some of our accomplishments and, given resources and time, some of the things we hope to do in the future.

To give you a perspective of the city, Tacoma is an older, medium-sized port city that has had almost all the social ills of American cities, but with more pizzazz. We provide all the services most cities provide and even run an airport and a railroad. In addition to extended controversy about the appropriate form of municipal government, we have had our Mother's Day riot, and our wonderful collapsible Galloping Gertie bridge. The salesman who insured the bridge had so much faith in the engineers that he pocketed the premiums, and when it collapsed he went to Brazil.

The Boeing Company, as most of you know, builds outstanding jet aircraft and space hardware, and does very well those things one typically thinks of as being associated with the aerospace industry. In addition, Boeing has dabbled in projects ranging from building personalized rapid transit systems to working with Alaskan natives.

Both Tacoma and Boeing got together because each of us was faced with a series of problems perceived to have solutions related to the other's resources. In the city we have experienced costs rising faster than our tax base, without a corresponding increase in productivity. Our street sweepers stir up and leave behind more street pollutants than they pick up. And our fire trucks—well, we have replaced the horse, but little else. In short, our available equipment is expensive, unreliable, and low in productivity. In addition, our software and paper flow processes are similarly antiquated.

While being confronted with its multitude of woes, Tacoma discovered it is located near a unique resource, the Boeing Company. After some discussion and activities we will mention later, we decided to learn whether the country bus from a small town could be happy as the wife of a Boeing 747. For Tacoma, the partnership has afforded the opportunity to improve the city's receptivity to the use of technology, increase its ability to apply technology, and provide better service for its people.

Concurrently with Tacoma's woes, the Boeing Company was faced with major changes in its business environment and was struggling to determine how it might best react to reduced airplane sales and lower military spending. It seemed that the development of new product lines and marketing of existing Boeing resources might develop new viable market areas. In developing and testing advanced technology systems such as the Minuteman Ballistic Missile and the 747 jumbo jet, Boeing had learned lessons that might lead to improved delivery of municipal services. While working with and contributing to the city of Tacoma, Boeing hoped to do three things:

1. Better understand city operations and equipment requirements.

2. Develop personnel capable of working effectively with city people.

3. In the long run develop profitable products and services to be sold on a commercial basis to municipalities throughout the country.

Boeing selected people from its organization who are noteworthy for their broad experience and a desire to contribute in a social environment. They were assigned to work on site in Tacoma on a full time basis. These technologists brought the know-how of sophisticated computer systems often used in aerospace, scheduling and planning disciplines, and skills in the applied physical sciences. Tacoma people contributed knowledge of the city organization and experience in providing services to citizens. In addition to the resources contributed by both Boeing and Tacoma, funding support was provided by the National Science Foundation's Intergovernmental Science Program.

The first time Tacoma and Boeing people got together, the city people were sure that the Boeing technologists would do something that would embarrass them or confront them with things they would not understand. The Boeing people are loath to admit it, but they were sure that municipal employees were a bunch of grafting politicians bellied up to the public trough. With this situation we decided that the equivalent of a typical American picnic would be a good way for people of both organizations to learn about each other. First, there was a big luncheon followed by a field day tour of the Boeing Aerospace plant at Kent, Washington. This provided the opportunity for Tacoma municipal personnel to go behind the guarded gates and see that engineers and scientists have coffee breaks, sit behind desks, and even use the same English language as city employees. Boeing then loaded up its people, took them to Tacoma, and did the same things—with some improvisations. Everyone was escorted to and locked in the Tacoma City Jail for lunch. Some have said it shook their faith in technology watching a Boeing vice president eating a tough Polish sausage with a spoon. (Obviously, no knives are allowed in the jail.) This was followed by a tour of several departments and demonstrations of some of the other services and equipment provided by the city.

Through these exchange visits, both Boeing and city people recognized each other as people having different skills which may be applicable to each other's problems. From this beginning we have seen the growth of the will, commitment, and feeling of responsibility required to begin looking at city problems. The list of accomplishments is long, but this presentation will focus on three major things now being done.

Transit Improvements

One of the first activities was to try to make improvements in the Tacoma Transit System. This operation manages to lose $1,700,000 each year above and beyond the fares paid by riders. It seemed that even go-go girls and free drinks could not increase the Transit System ridership. About the only people who ride the transit are the no-alternative folks—the halt, lame, blind, young, old and poor. The problem was to figure out how to continue providing services for these people while at the same time reducing the yearly deficit. Through the efforts of the technologists and transit system personnel in coupling their skills, two new ways of improving the situation were conceived.

One related to the fact that on a standard route, buses maintain a specified headway between themselves. The headway is the time between service at any particular bus stop. This means a bus will run by a particular bus stop every hour, half hour or 20 minutes. But the total bus route is usually not evenly divided by the headway. Thus the buses must wait somewhere, usually at the end of the line, until it is time to start out again. I am sure you have all seen a bus driver sitting in an empty bus at a bus stop reading a newspaper. He is not loafing, but merely waiting for the proper headway.

After building an extensive model of the transit system it was discovered that at any given time at least two buses were waiting for the proper headway throughout the city. From this it seemed reasonable that if we could pool all waiting time in the central business district, where the buses originate, we could take the first available bus and start it out on the first available route. This would not necessarily be the route it just completed. The resulting reduction of waiting time would in effect eliminate two buses from the system at about $12.48 an hour.

The second thing examined in the transit system was a real money-losing segment of the operation. This is the part from 7:30 p.m. to midnight. There are 14 buses on 14 routes with minimum one-hour service, averaging 750 riders a night, Monday through Friday. The loss during this time period is approximately 80 cents per rider. We are now working on the development of a dynamic routing system. This will allow buses to be freed from their fixed routes and follow specially designed routes determined by user demand. A person who wishes to ride a bus during this time period will call a transit dispatcher, tell him where he is, where he wants to go, and at what time. This information will be fed into an on-line computer system which will tell the rider where and when the next bus will be available. The computer will compile a route linking all the riders in a certain area, and the dispatcher will then radio the route to the bus driver. As he proceeds along this route, the bus driver will receive a continual update of changes. Those passengers who ride every night will be preprogrammed into the system, and casual riders will be inserted into the system as they call in. It appears that the number of buses required can be cut in half and the financial loss reduced by almost two-thirds during the evening hours.

Court Scheduling

The second project to be discussed involves a municipal court scheduling technique. Upon pleading not guilty in traffic court—at least in the State of Washington—a defendant has the right to be confronted by his accuser, the police officer making the arrest. Police officer witnesses are paid 2½ hours minimum overtime for each time they must appear in court. It seemed that the city was paying excessive overtime resulting from the large percentage of cases requiring court appearances by police officers. This amounted to approximately $90,000 in overtime costs last year.

The city wanted to reduce the amount of overtime but, quite frankly, was afraid to tackle the situation. There is a rule in municipal service that if you do the same old thing and it goes wrong, it's an act of God. But if you do something different and it goes wrong, it's your fault. This was a particularly touchy situation because of the number of independent organizations and persons involved: the citizens, the attorneys, the police and the court. The City Council would certainly not look favorably on any activities that antagonized the judges, the citizens or the police union.

By working together, the Boeing technologists and the municipal court administrator built a computer model of the municipal court system. The use of this model in effect increased the number of court cases for which an officer would be a witness per court appearance. The result was a reduction in the number of total appearances for an individual office and thereby in the amount of overtime. After working out the bugs and coordinating the activities with all affected persons, the system was put into operation. The city has yet to receive a complaint, and the overtime costs have been reduced to about $40,000—less than half of the former total.

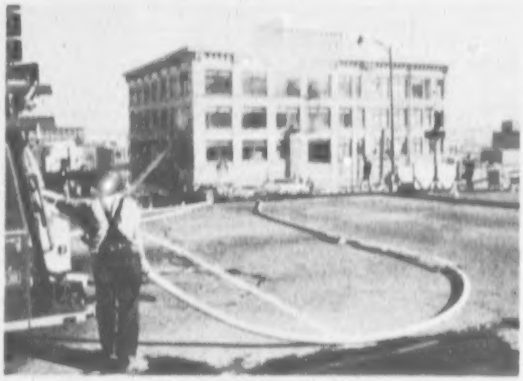
Testing Fire Hose

The third project we want to mention involves implementing the use of 5-inch-diameter fire hose. In European countries, fire hoses up to 6 inches in diameter have been in existence and use for some time. They are light weight and have light weight couplings, but have not been used extensively in the United States. And the probable reason is they don't meet some dingy requirement of the National Fire Protection Board. The Tacoma Fire Chief wanted to try the hose, but before investing substantial funds he wanted performance data. In Municipal service, performance data are like fairy tales—useless fables. Boeing showed the city how to run some tests that would indicate the usefulness of the hose and its durability and safety.

To give an idea of the difference between using a typical hydrant hookup and a large diameter hose hookup the photographs show each being used at a two-alarm fire in an older department store in downtown Tacoma. The fire involved about 20 per cent of the building. At the time these pictures were taken, eight fire companies were discharging about 3,000 gallons of water per minute.

Figure 1 shows what is called a typical full hydrant hookup. A 6-inch diameter soft section line is connected between the hydrant and the pumper at the left. The pumper discharges into one 3-inch line and two 2½-inch lines, which go to a second pumper located directly in front of the fire. The pumper at the hydrant increases the pressure in the three discharge lines to overcome friction loss between the first and second pumpers. The second pumper in front of the fire increases

Figure 1

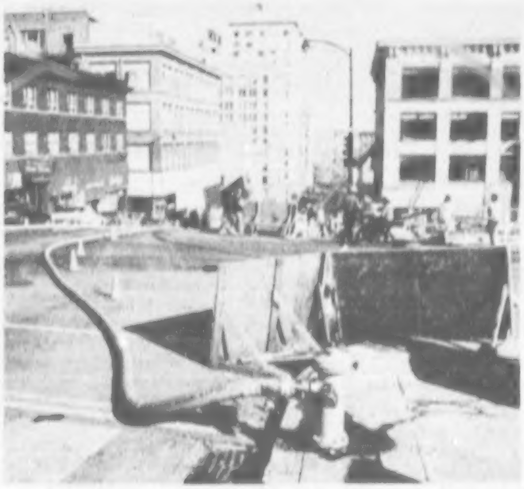


the pressure of the water and discharges into hand lines used by firemen in fighting the fire. An additional man is required to watch the second pumper.

This first picture represents the typical hydrant hookup system used in most American cities. The fireman leaning on the hose is performing a vital function—watching the pumper at the hydrant. Using this system, two engines and two men are used in addition to three separate hoses. Time is required to lay each of them.

Figure 2 shows a 5-inch-diameter hose hookup located, coincidentally, directly across the street from the standard hookup at the same fire. In making this connection, an engine drove to the hydrant and dropped a man at the hydrant to connect the 5-inch lightweight hose with a quick-connect coupling. Because the engine was not needed to pump at the hydrant to overcome friction loss, it went on to the fire and pumped the water directly into the hand lines. Upon compleing the hydrant hookup the man assigned to this task was able to proceed to the fire and perform other fire fighting duties. This system requires the use of only one pumper and one man to watch the pumper. It delivers the same 1500 gallons of water per minute to the fire scene as does the standard hookup. Because of the success of this project last year, we reduced the firemen's work by two hours a week. This was done on a negotiated agreement with the union, without adding any firemen. The City Council has now appropriated more than $300,000 to convert all hydrants in the city to accept the quick-connect large-diameter hose connectors.

Figure 2



Other Activities

In addition to the projects already mentioned, Boeing technologists are involved in activities with the city to help the police develop communications specifications and select equipment, to work with the Public Works Department to improve refuse collection and disposal and to aid the Traffic Division in forecasting and scheduling traffic lights and traffic flow. They have also supported Police personnel in developing flame resistant specifications for the city jail. This last activity was undertaken because of a disastrous fire in the city jail several months ago. It was only due to extremely good luck that five prisoners and nine policemen were not overcome by smoke and suffocated. Because of Boeing's great experience in working with fire-retardant paints and flame-resistant materials, a reservoir of technical expertise was readily available to help better fire-proof the city jail.

One of the findings from the Tacoma and Boeing people having worked together might be useful to those who are looking into technology transfer. It is that the hardware and projects involved are not as important as the process of interaction between technologists and city personnel. We refer to the development of productive relationships between technologists and city people. It involves enabling each to learn about the other and how to deal with them. For example, one thing that surprised many of the city people was finding that technologists and Ph.D.'s are really fairly useful. We found also that sitting back and trying to identify all the bars to technology that exist is like saying that people who work in cities are incompetents, who don't want to change and improve. The Boeing people would be among the first to point out that this isn't true—that city people really do care about what they are doing and that they really need and want technological help. The better and more effective approach is to focus on the process of technology transfer—trying to develop ways in which technologists and city personnel can function together as a team.

As a Boeing/city team we have both realized that far more projects have been identified than we know what to do with. Furthermore, the need for technological advancement far exceeds the resources either organization is able to contribute to the research effort. To have any significant impact in improving the application of technology to the delivery of municipal services, it is clear that an enormous amount of manpower will be required over a long period of time.

When approaching Federal agencies for financial support, we have found it is a lot easier to get them to support software research, studies, and such, rather than hardware. When you write a report, no one can say you didn't do it; because there it is, and one can argue only with the validity of the contents. But if you build a fire hydrant opener it either works or it doesn't. And some of the folks we deal with are not too interested in answering that question. Working together, we have come up with a number of very imaginative ideas like redesigning fire equipment, trash equipment, and street sweepers. We would like to undertake the projects. But these are projects that are really beyond the capability of the city because it lacks the technical expertise, and they are beyond the capability of industrial organizations like Boeing because they lack the experience of providing services. But as a team it seems clear that an enormous amount of progress can be made in developing much needed hardware.

Bill Donaldson relates that when he was a lad, he thought he was going to be an Episcopal priest. He went to seminary and found out about half way through that the only possible way he could ever pass Greek was to become very, very friendly with the Dean of the seminary. He used to go around with the Dean, Father Fielding, whenever he gave talks to young people's church groups. Father Fielding had one of the most frightening talks about marriage ever heard. He would tell about the financial problems of marriage, the mother-in-law problems, and, "Don't spend your whole life in bed." When he was done with this, nobody who had paid attention would ever want to get married. But in the back of the room, his wife would jump up and say, "Charlie, you didn't tell them how much fun it is!"

And that is what we have learned working together as a Boeing/Tacoma team: There are a lot of problems, and a lot of difficulties, but it is just an awful lot of fun. And we can really accomplish something that helps improve the delivery of services to people.

Private Sector Productivity

RANN APPROACH TO PRODUCTIVITY RESEARCH — PRIVATE SECTOR

Holt Ashley
Director
Advanced Technology Applications Division
National Science Foundation

Having just returned from a vacation trip that took me to some of the less-developed regions of the West Indies, I had it brought home to me once more how incredibly important to the quality and richness of life in America is the factor of productivity. It is no accident that the enhancement of productivity, in the broadest sense of this term, forms one of the principal themes for RANN-supported research.

Already described is the four-part categorization devised for the substantive content of all RANN programs: Energy, Man's Impact on the Environment, the Effects and Hazards on Man and His Works Due to the Natural Environment, and Productivity.

Having covered Productivity in the public sector, we now turn to the private sector of the U.S. economy. Progress reports from three relevant and maturing projects under the cognizance of the Division of Advanced Technology Applications follow. Each is focused on industrial productivity.

Technological Opportunities

One of the two main responsibilities of this division concerns technological opportunities. In general and under the broad umbrella of the RANN research guidelines, these constitute opportunities for improved productivity and resource utilization that are highly technology-intensive, but yet are *not* concentrated on the generation, transmission, storage or conservation of energy. The latter, of course, have formed a distinct focus in the symposium (and RANN) program.

Let me begin by furnishing some background for our current spectrum of activity in technological opportunities. Then I shall mention one of the plans we are laying for the future.

Until quite recently, the state of affairs in most rapidly developing industrial countries—including the United States and all of Northwest Europe—was characterized by ready, inexpensive access to apparently unlimited energy and nearly all key raw materials. This was combined with a relative manpower shortage but swiftly increasing educational capital. A simple index of productivity was adequate to measure the efficiency of such an economy, and it consisted of value in goods and services produced by person-hour of labor. Until just a few years ago, this index was substantially higher in the U.S. than in any other nation. But consider the changes. For example, during the decade 1960-1970: in the U.S., this index increased about 30 per cent; at the same time in West Germany and Japan, respectively, it increased by 80 per cent and over 190 per cent of the 1960 base level! Moreover, wages are going up much faster than output in our country today.

Obviously, the scarcity of labor created (as it still does) a strong drive to increase man-hour output through investing capital in labor-saving and man-amplifying production machinery, as well as through man-replacement by automation. Here is the motivation for, among others, RANN's program element called Advanced Industrial Automation.

But a new factor is becoming more apparent day by day, as the news media never seem to let us forget. Those raw materials—that is, the resource base for a modern and wealthy economy—are a long way from being infinitely available. Liquid petroleum is prominent in our thinking today, but it is only a bellwether.

As a consequence of this and other shortages, many of us now see compelling reasons for using those resources accessible to us much more efficiently. Typical strategies to this end include various conservation measures, reclamation, more efficient chemical and physical conversion of substances, higher-yield processing *and* reprocessing of ores, etc. Certain activities of this kind have already been discussed in connection with RANN's Energy programs. Others fall under the Advanced Technology Applications Division, a notable instance being the MIT National Magnet Laboratory's work on ore beneficiation, to be covered in a paper that follows. Yet another concerns the comminution and removal of rock and soil, at reduced cost in labor and energy. This forms the objective of our entire program element in excavation and tunneling technology.

Future Possibility

Now a few words about some future possibilities, as they are beginning to emerge from our program-development activity. A study is now being conducted for RANN by MARCOM, Incorporated, of Los Angeles. Through the mechanism of interviews with senior executives and others, MARCOM is identifying particular areas (i.e., the rolling of steel) where there are unusually promising opportunities for increased industrial productivity.

ENZYME ENGINEERING IN THE FOOD AND CHEMICAL INDUSTRIES

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and
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Philadelphia, Pennsylvania

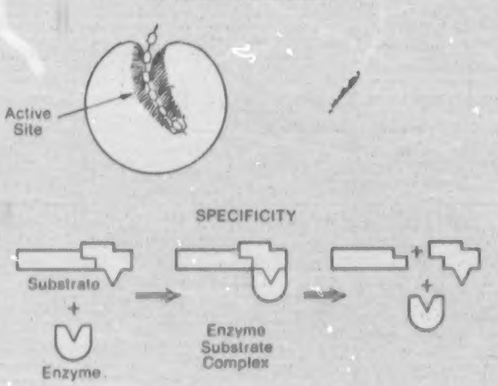
Enzymes may be the most studied yet underutilized substances that exist today. The reasons for this are simple. Pure research in biology and biochemistry has received support totalling many billions of dollars. A major focus of this research has been enzymology, since enzymes are the substances that catalyze and ultimately regulate all life processes. If this huge research expenditure is to be economically justified it must be applied to practical problems. Although some of the applications of enzymes in medicine have received wide attention, particularly in diagnostic procedures, a disproportionately small effort has been made to convert the results from these pure research programs to useful technology.

The major intent of research in enzyme technology is to provide the techniques necessary to exploit the extensive results of basic research in the life sciences for the public good.

What is an Enzyme?

Enzymes are biological catalysts. They regulate all life processes. They are products of living cells. They are high molecular weight proteins containing 125 to 3,000 amino acid residues. (There are 20 different amino acids in nature. This means that there are at least 20^{125} or 10^{162} possible enzyme combinations. We should note that there are only 10^{103} molecules in the universe. The age of the universe is 10^{17} seconds, and 10^{40} codons have been read on earth. Thus we can conclude that there is a lot for the enzyme technologist to do.) Their structure is ultimately dictated by DNA, the genetic material of the cell. Enzymes are generally globular in shape. One example is lysozyme, containing 126 amino acid residues, illustrated in Figure 1. They usually contain a cleft where the active site lies and where the substrate specificity is expressed. Enzymes have a high specificity which frequently is so great as to distinguish between stereoisomers. This specificity in action has been likened to a "lock and key" type of reaction. More than 2,000 enzymes have now been identified; perhaps 100,000 may exist.

Figure 1—Lysozyme
126 Amino Acid Residues



Why the Recent Upsurge in Enzyme Technology?

Until recently the predominant commercially exploited enzymes were those produced by microorganisms outside the cell. They were the "digestive" enzymes of microorganisms (i.e., they functioned by catalyzing the hydrolysis of materials such as starch, proteins and fats). This class of enzymes is known as the hydrolases. It represents only one of the six major classes of enzymes, which are listed in Table I. They are all relatively cheap to produce and require no coenzyme as do the other classes of enzymes. Hence, neither re-use nor regeneration is necessary for their economic exploitation. Commercial utilization of these other enzymes had to be delayed until major breakthroughs occurred in the development of techniques for their production and use.

Table I —**Classes of Enzymes**

Enzyme Class	*Operation Catalyzed*
1. Hydrolases	Hydrolysis
2. Oxidoreductases	Oxidation-Reductions
3. Transferases	Group Transfer
4. Lyases	Group Removal or Addition to Double Bond
5. Isomerase	Isomerization
6. Ligase (Synthetases)	Joining Molecules at the Expense of High Energy Bonds

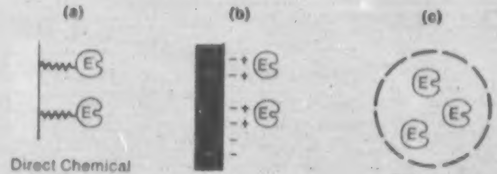
What Were These Techniques?

Three key recent advances have set the stage for full exploitation of enzymes. These are:

- **Development of genetic techniques to cause microorganisms to produce super quantities of desired enzymes.**
- **Development of chromatographic techniques, particularly gel and affinity chromatography, which allow one-step recovery with thousand-fold purification of a particular enzyme.**
- **Development of techniques to immobilize active enzymes and their cofactors, thus stabilizing and permitting the re-use of expensive enzymes.**

Enzyme immobilization techniques are especially important to the newly emerging enzyme technology. The three basic methods of immobilizing enzymes are illustrated in Figure 2.

Figure 2—**Methods of Immobilizing Enzymes**



Direct Chemical Linkage or Covalent Bonding

Adsorption

Entrapment or Encapsulation

- **Attachment to an inert material by direct chemical linkage such as through a covalent bond.**
- **Physical adsorption on a particulate material and then cross linking the enzyme to form a kind of enzyme skin or membrane.**
- **Entrapment in a matrix by inclusion in a gel, as it is formed, or encapsulating the enzyme in a microcapsule.**

These techniques were developed for the most part in Japan and Europe. However, the alertness that led to recognition of the resulting new potential for enzymes, plus quick infusion of several millions of dollars into enzyme technology research by the National Science Foundation and certain U.S. companies, has now permitted the United States to assume a world leadership role in enzyme utilization research.

It is essential to sustain this leadership because of the valuable contributions that enzymes are making and can make to U.S. productivity, to control of the environment, to health care delivery and to energy conservation.

In a study for the N.S.F., annual enzyme sales in the U.S. were estimated to be on the order of $35 million and would rise to around $58 million by 1980. Details are in Table II. Unfortunately, this study focused almost exclusively on the hydrolytic enzymes. It neglected the other five classes of enzymes that require cofactors for their use. It neglected consideration of enzymes in medical treatment and therapy. It failed to realize that the incremental increase in the Gross National Product brought about by the processes that these enzymes have made possible is important, not the increased value of enzyme sales. Clearly this GNP increase is on the order of several billion dollars annually.

Let me illustrate this point with two key examples. One is a new process and another is

Table II —Total U.S. Markets
($ Millions)*

Enzyme Group	*1971*	*1975*	*1980*
Amylases	8.31	12.50	14.20
Proteases	18.34	20.77	24.51
Glucose Isomerase	1.00	3.00	6.00
Celulase	0.10	0.15	0.20
Glucose Oxidase	0.35	0.60	0.90
Pectinase, Invertase, Etc.	1.66	1.85	2.10
Co-Factors	—	—	?
Medical			
Diagnosis & Research	5.50	7.30	9.80
Treatment	—	—	?
	35.26	45.42	? > 58

*This only refers to enzymes and not to processes they catalyze. This market is estimated to be between 10-20X enzymes costs, i.e., around $\$1 \times 10^9$.

a medical treatment, both made possible by enzymes.

The first process utilizes the enzymes amylase and amyloglucosidase to hydrolyze domestically produced cornstarch, converting it to dextrose syrup. Then with the use of the enzyme isomerase, the dextrose is converted to glucose and fructose syrup. If the enzymes can be used repeatedly, it has been estimated that the cost of the resulting sweet syrup would be 8-9 cents a pound. This compares with 13 cents a pound for invert syrup obtained from cane sugar—of which 60 per cent is imported. The savings to the United States in import dollars could amount to $800 million a year, not to mention the creation of new industry and jobs plus savings that could be passed along to the consumer.

With respect to medical treatment made possible by enzymes, more than 20 million persons suffer from gallstones in the United States. Many have these removed by costly surgical procedures. A chemotherapeutic treatment has recently been developed. This involves treating the patient with oral dosages (½ gram per day) of chenodeoxycholate over a six-month period to dissolve the gallstone. At present, the cost of the agent is $800/100 grams or roughly $1,200 a cure. A new two-step enzymatic process for the production of chenodeoxycholate has been discovered. It holds promise for producing chenodeoxycholate at a price which would reduce the cost to around $30 a cure. This represents a potential savings of around a $1,000 for each of 20 million persons in the United States alone, who might seek a chemotherapeutic cure of their gallstone troubles, not to mention the relief from very debilitating surgical procedures.

Ongoing Research

Let us now focus on what is happening in enzyme technology research in order to point to what the future may hold for enzyme utilization.

Several RANN-supported research groups in the U.S. have recognized that the valuable characteristics of enzyme catalyzed reactions will be reactions involving highly specific dehydrogenations, hydroxylations, phosphorylations and group transfers. Enzymes catalyzing such reactions almost invariably have a requirement for a coenzyme, or cofactor as it is sometimes known. A problem in using these enzymes is that coenzymes are frequently as expensive as the enzymes themselves. A second problem is the necessity to remove the coenzymes from products of the reaction.

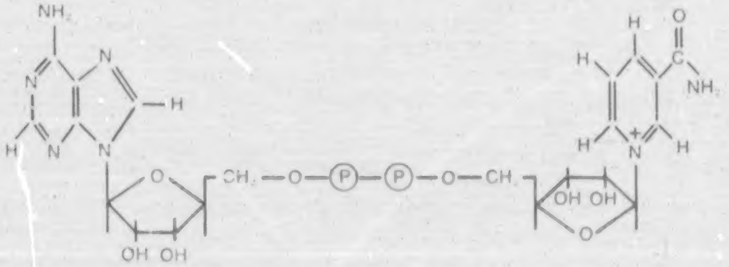
The RANN-supported Enzyme Technology group at the University of Pennsylvania has successfully solved this problem in the case of dehydrogenase enzymes by covalently coupling the pyridine nucleotide coenzyme, NAD, to large molecular weight polymers. A number of important problems had to be overcome before this could be done.

First, it was essential to immobilize the coenzyme by attachment at a site in the molecule that did not interfere with its reactivity in the enzymatic reaction.

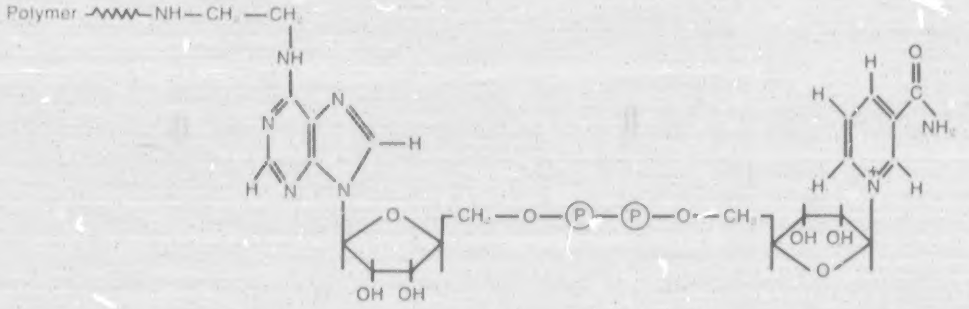
Second, the coenzyme polymer complex could not be too large; otherwise it would not be able to interact with the enzyme. The solution we achieved was to covalently couple NAD to soluble polymers of approximately 50,000 M.W. Thus, we are now able to retain coenzymes in membrane reactors. Substrates enter and products leave these reactors through high-molecular-weight cut-off membranes.

Figure 3 shows the structure of NAD and the specific manner in which we attach this molecule to a high molecular weight polymer. Figure 4 shows how it reacts in a typical dehydrogenation reaction.

Figure 3—**Coenzyme Structure**

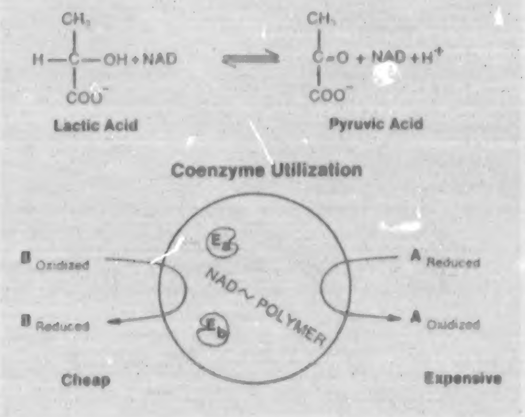


Free NAD



Bound NAD

Figure 4—**Coenzyme Action**

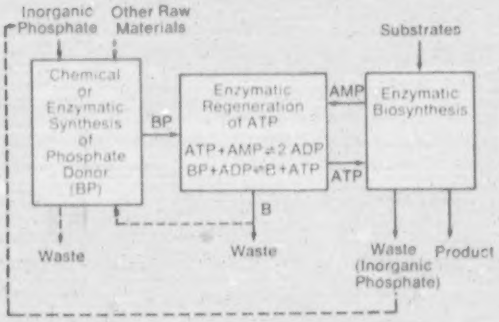

Lactic Acid
Pyruvic Acid
Coenzyme Utilization
B Oxidized
B Reduced
A Reduced
A Oxidized
NAD～POLYMER
Cheap
Expensive

As can be seen in the figure, for every molecule of pyruvic acid produced, one molecule of NAD is converted to a molecule of NADH. For the continued production of pyruvic acid by this method it is necessary to regenerate the NAD continuously from NADH. Fortunately, we have also solved this problem. There are a number of inexpensive enzyme systems that can be added to the reactor and which will continuously regenerate the oxidized coenzyme.

This significant advance in the re-use and regeneration of coenzymes opens up the possibility of commercial application of enzymes such as the dehydrogenases and hydrolases. We are presently continuing research on the application of these enzymes and immobilized coenzymes in pharmaceutical production (chenodeoxycholate and modified steroids) and fine chemical production (β-keto adipic acid) from cheap starting materials.

Working along similar lines a RANN-supported group at the Massachusetts Institute of Technology is looking into the possibility of the complete synthesis of an antibiotic by enzymatic methods. The synthesis of this antibiotic, Gramicidin S, uses enzymes that require the coenzyme ATP. ATP operates as a phosphate donor in these reactions and must be regenerated by being rephosphorylated. The MIT group has solved the regeneration problem by the use of relatively cheap chemicals and is investigating the re-use problem by immobilizing ATP to a polymer in an identical manner to that developed by the University of Pennsylvania group for NAD. Figure 5 shows several ways in which ATP can be regenerated relatively cheaply.

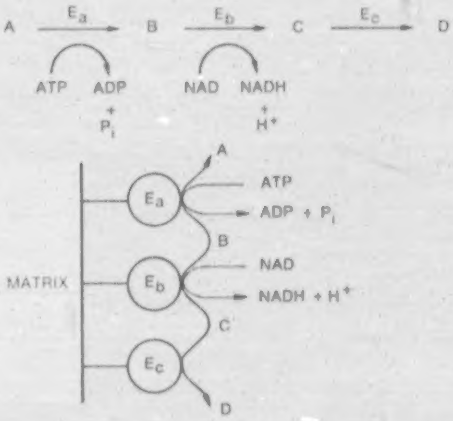
Figure 5—**Enzymatic Synthesis with Enzymatic Regeneration of ATP**


Inorganic Phosphate
Other Raw Materials
Substrates
Chemical or Enzymatic Synthesis of Phosphate Donor (BP)
BP
Enzymatic Regeneration of ATP
ATP+AMP⇌2 ADP
BP+ADP⇌B+ATP
AMP
ATP
Enzymatic Biosynthesis
B
Waste
Waste
Waste (Inorganic Phosphate)
Product

These two examples of how problems in the application of coenzyme requiring enzymes are being solved demonstrate the innovative and forward-looking nature of the RANN-supported research in enzyme technology. The results of this research now open up the possible commercialization of a whole host of valuable processes which have little energy requirement, are highly efficient, and have high economic benefits.

Many of these commercial processes will involve sequential conversion of a cheap raw material into a valuable end-product. Figure 6 attempts to illustrate how this might be accomplished.

Figure 6—**Multistep Enzyme Reaction**


A
E_a
B
E_b
C
E_c
D
ATP
ADP + P_i
NAD
NADH + H^+
MATRIX
E_a
E_b
E_c
A
B
C
D
ATP
ADP + P_i
NAD
NADH + H^+

We are presently working on one example of such a sequential process at the University of Pennsylvania. Phenol, a by-product waste material of many industries, can be converted by a sequence of enzymatic reactions to a very costly chemical, β-keto adipic acid. Five separate and sequential steps are required to do this.

The figure illustrates how a three-step sequential reaction scheme might be carried out with immobilized enzymes. Because of the vast number of different enzymes that exist in nature it may soon be possible, if the current pace of research is maintained, to evolve many chemical production schemes by highly efficient multi-enzyme systems.

The Future

The future for enzyme applications seems almost unlimited. All of the reactions carried out by nature can potentially be duplicated in the laboratory plant. Some applications sure to occur are:

- **Enzymatic synthesis of nutritionally important amino acids for upgrading foods.**

  A number of research teams have recently reported interest in converting α-amino caprolactans to lysine (a key nutritionally limiting amino acid) in two enzymatic steps. In this manner one can convert inexpensive raw materials into a biologically important compound and at the same time eliminate the fermentation wastes of existing processes.

- **Synthesis of medically important chemotherapeutic agents.**

  One of the unique and exceedingly important aspects of enzymes is their ability to catalyze stero-specific reactions. Products of these reactions are extremely important as pharmacological agents. The *in vitro* use of enzymes for synthesis of chemicals such as chenodeoxycholate is an extremely important prospect for enzyme technology.

- **Cofactor regeneration for synthesis.**

  Cofactors will find use, particularly in this era of the energy crunch, in low temperature, low pressure enzyme catalyzed synthetic reactions.

- **Enzymatic utilization of high energy bonds in chemical synthesis.**

  Enzymatic processes offer a way to utilize the chemical energy from cheap renewable resources for the production of expensive chemicals.

- **Degradation of solid wastes.**

  Many solid waste materials, such as cellulose and lignin, are amenable to hydrolysis by enzymatic means. It may be possible, therefore, to facilitate by enzymes the conversion of these wastes to useful materials and fuels.

- **Degradation of oil spills.**

  Enzymes can speed the breakdown of hydrocarbons by catalyzing the first step in their oxidation, thus making it possible for the natural microflora of the soil or surface water to finish the job.

- **Enzymatic treatment of diseased and damaged living systems.**

  Immobilized enzymes can be implanted in living systems to overcome various metabolic diseases or abnormalities. Most certainly an enzyme shunt to assist a damaged kidney or liver is feasible now.

- **Development of acoustically sensitive enzyme systems for medical holography.**

  Acoustically sensitive enzyme systems appear technically feasible. If this proves so, they offer an alternative to liquid crystals as acoustical detectors and may provide a way to achieve a kind of 3-dimensional X-ray.

- **Development of photo-sensitive enzymes for film systems.**

  Certain enzyme systems are photoactivated. These systems offer an alternative to existing photographic and light detection systems.

This list could go on. However, for purposes of this paper it is sufficient to illustrate that the future for enzyme technology is very bright.

Conclusions

Recent major breakthroughs in enzyme production, recovery and immobilization have created the potential to utilize a whole new class of enzymes—those occurring intracellularly and requiring cofactors. These enzymes, previously too expensive to consider in practical applications, have important potential uses in creating new processes, in control of the environment, in health care delivery systems, and in energy conservation. They have the potential to generate billions of dollars of new industry and to help equalize our balance of payments. The U.S. lead in enzyme technology must be maintained. Hopefully, enzyme technology will not end up as another one of our technological "give-aways."

AUTOMATION IN MECHANICAL MANUFACTURING INDUSTRIES

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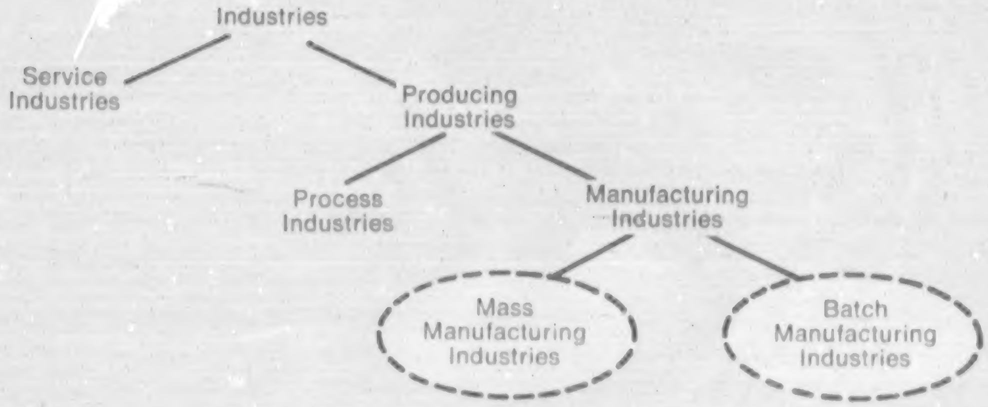
RANN's activities in industrial automation are modest in scale and recent in origin. But they are likely to grow and to play a catalytic role in enhancing our nation's productivity and general industrial effectiveness. To understand what RANN is doing, and why, a categorical model of modern industry is helpful. The crude binary tree shown in Figure 1 will serve our purposes.

Observe first that industries can be distinguished by whether they produce tangible goods or provide services, such as health care or education. We shall concentrate on the producing industries because they are more amenable to automation through relatively "pure" technology. While the fraction of the populace employed in the producing industries has decreased slowly for decades, it is still more than one quarter of our 90-million-plus working force. (Service employment has risen as producing employment has declined. Although the service industries seem to be much harder to mechanize and automate, the potential rewards for success grow larger each year.)

The producing industries can be divided into process and manufacturing industries. Loosely, process industries produce such "continuous" goods as petroleum products and paper, whereas

Figure 1


Industries
Service Industries
Producing Industries
Process Industries
Manufacturing Industries
Mass Manufacturing Industries
Batch Manufacturing Industries

the manufacturing industries produce discrete products—cars, shoes, generators, and so forth.[1] Far more people are employed in manufacturing than in the process industries, mainly because the latter have lent themselves readily (for reasons we shall note later) to extensive mechanization and automation.

The manufacturing industries can be divided, again crudely, into mass and batch manufacturing industries. The distinction is based on the quantities of similar items produced and on the flexibility of the production facilities. Mass manufacturers make thousands (or millions) of shoes, cars, and refrigerators using specialized machines, whereas batch manufacturers make small numbers of items (typically one to a few hundred) using relatively general-purpose machines. An amazing variety of goods, ranging from capital equipment (machine tools, generators, jet transports) to luxury consumer items (fine furniture and jewelry), is batch-produced. Estimates of the volume of batch manufacturing have run as high as 75 per cent of all manufacturing, but definitive figures seem to be unavailable.

Manufacturing of discrete products has two distinct phases: manufacture of component parts, which is often dubbed "discrete part manufacturing" or simply "manufacturing," and secondly, assembly of parts into products. While a host of related activities must also occur (e.g., inspection and material handling) part making and assembly are the two really basic phases of product manufacturing.

Batch and mass manufacturing differ in the character of their part making and assembly operations, and the differences trace back to product design. Batch-produced industrial products are designed mainly for functionalism; they tend to have numerous but relatively regular parts whose manufacture and assembly are both custom operations. Mass-produced products are designed for manufacturability as well as for functionalism. They often have fewer but more complex parts, because the extra design and tooling costs for complex parts can be recovered through savings in assembly-line labor. The differences can be seen by comparing the convoluted stampings inside an automobile with the relatively regular machined and cast parts of a machine tool.

RANN Projects in Industrial Automation

RANN's small suite of current projects is mainly concentrated in the two basic phases of manufacturing cited above, i.e. part manufacturing and assembly.[2] The assembly projects are concerned mainly with manipulators ("robots") for assembly line service in mass manufacturing, whereas the part making projects are aimed at batch production environments. Thus both types of projects are attacking areas of manufacturing which have high labor content.

RANN's activities in industrial automation began to take shape in 1971, when the nation's foreign trade deficit was swelling rapidly toward its 1972 peak. There was a growing clamor at that time for improved productivity, tariff protection, or both, especially in those goods producing industries that were most vulnerable to foreign competition. Thus automation projects were encouraged and selectively funded, and projects that showed promise of yielding flexible results broadly applicable to labor-intensive activities were favored.

The passage of two-plus years and some favorable changes in our trade figures have provided additional perspectives both for RANN and for its investigators. Happily, the directions taken initially still appear to be sound, and the trade reversal has provided some breathing space in which projects can aim for results that will be useful in the intermediate, as well as in the immediate, future. The recent foreign trade reversal, however, most assuredly does *not* indicate that America's productivity problems have been solved. The reversal is attributable mainly to severe dollar devalutions which have reduced our relative standard of living, and to unusually large commodity exports that may be non-recurring. Indeed, our relative (to our major competitors) industrial productivity has continued to decline over the past few years if changes due to devaluation and revaluation of currencies are removed.

But there is more to automation than productivity. Popular articles on automation cite such additional advantages as improved part/product quality and speedier responses to the market place. These and other attributes all can be lumped into the word *control*. To automate manufacturing, one must understand manufacturing deeply: when it is so understood, it will be controllable in ways that are impossible now except through "seat of the pants" judgments. Manufacturing parameters potentially subject to close control through automation (and probably only through automation) include, in addition to quality and through-put, energy and material consumption—two topics likely to be more important in the 1970s and 1980s than in the 1950s and 1960s.

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[1] The model at this level is almost too crude. To see why, readers should attempt to categorize the multifaceted food industry, and the construction and extractive industries.

[2] At this writing, relevant projects aimed at assembly automation include those at Stanford Research Institute (Charles Rosen), the Charles S. Draper Laboratory (James Nevins), and latently at Stanford University (Jerome Feldman). Projects directed at part manufacturing in addition to that of the present authors include those at Case/Western Reserve (Harry Mergler) and I.I.T. Research Institute (Survey: Hunter Shu).

Thus far, then, we have productivity and enhanced controllability of manufacturing as the broad goals of RANN's industrial automation program. There is a third goal of great long-term importance . . . in many ways a *sine qua non*. It is, succinctly, the creation of a scientific base for manufacturing.

The fact that manufacturing lacks a scientific base is both surprising and generally unacknowledged. It can be appreciated by comparing manufacturing with the process industries. Petroleum refineries, petrochemical plants, paper mills and the like employ significantly fewer people per dollar of product produced and have significantly higher capital investment per employee. Why is this so? Much of the answer lies in the simple fact that engineers have understood these industries. They had increasingly good analytical models for flow processes, and thus were able to design plants in the 1930s, 1940s and 1950s for "classical" servo controls, and in the 1960s and 1970s for computer controls.

Analogous models for discrete manufacturing simply do not exist except in isolated cases. Manufacturing runs today much as it has for two centuries: on the skills of many millions of people.[3] The situation is unlikely to change markedly until mathematical models are evolved for whole phases of manufacturing. The development of such models is applied science in the classical sense: without them, manufacturing cannot be understood deeply enough to automate systematically, and yet the models themselves cannot be developed until manufacturing is understood. We shall have more to say on this later.

In summary, RANN's industrial automation activities have three broad goals: productivity improvement, controllability enhancement, and the laying of a scientific foundation for all such work.

Productivity and Its Effects

Because productivity and its effects are sometimes misunderstood, a few comments on the subject are appropriate.

History teaches us that man learned first to communicate, and, through communication, he learned to organize his activities and, later, to deploy technology. The marriage of technology and organization led to modern industrial societies.

A signal result of man's ability to organize and to use technology has been, and continues to be, the ability to *redeploy resources* for new purposes without diminishing his material standard of living. This is what productivity improvement really means: freeing resources for redeployment. The freed resources are of course labor and capital dividends created through reinvestment.[4]

It is important to understand resource redeployment, because many people today are deeply concerned about social and environmental problems and are clamoring for resources to apply to such problems. Not everyone realizes, however, that social and environmental programs consume rather than create resources, at least in the short run. Such materially counterproductive programs therefore must be balanced—if we wish to preserve our standard of living—by productivity-enhancing programs. The authors believe that a balance has not yet been struck in programs sponsored by the Government, but at least the trend may be favorable in RANN.

The Production Automation Project

This RANN-sponsored project was inaugurated in mid 1972 and is directed at mechanical part manufacturing in batch environments. The project is sited in the College of Engineering at the University of Rochester, with Gleason Works of Rochester as the principal industrial collaborator.[5]

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[3] Bernard Chern aptly characterized manufacturing as "experience based," rather than science based.

[4] Some people read "unemployment" for "redeployment." Unemployment certainly can occur, but history again teaches that it is transitory and progressively less painful, even for those affected directly, as the effects of technical change come to be understood and brought under social control. For a provocative view from the left, see pp. 68-89 of M. J. Cooley's monograph, "Computer Aided Design . . . ," available from the Amalgamated Union of Engineering Workers, Onslow Hall, Little Green, Richmond, Surrey, England.

Automation of almost any process is primarily an exercise in information processing. To gain insight into the types of information that are used in modern mechanical batch manufacturing, let us look briefly at how parts are made today at Gleason Works, because Gleason's practices are representative of those in hundreds of other firms.

A part begins as a concept that a draftsman (Figure 2) translates into a detail drawing as in Figure 3. The drawing becomes the documentary definition of the part, and on it are based essentially all subsequent operations needed to make the part.

Figure 2

The first of these is process or operation planning, which is done by a process engineer (Figure 4), who devises what might be termed a "strategic plan" (Figure 5) for the part's manufacture. The plan is passed to part programmers (Figure 6) and others who devise the "tactics" needed to execute each operation specified in the process plan.

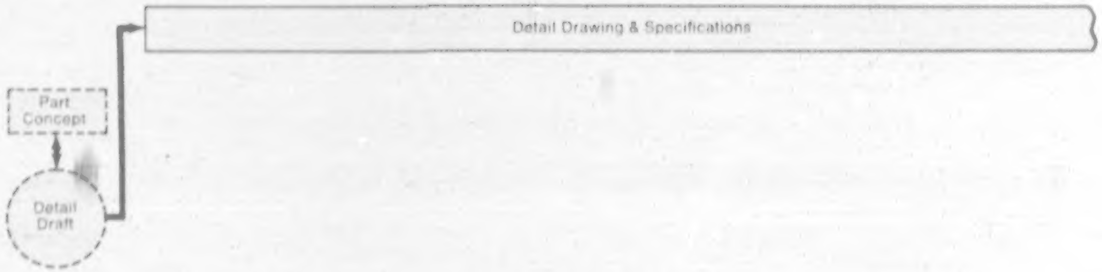
In most modern firms, many of these "tactical plans" are prepared as part programs (Figure 7) for numerically controlled (NC) machine tools. Part programs usually must be entered into a computer (Figure 8) for translation into control tapes for NC tools.

At this point, essentially all of the information needed to make the part has been generated. It is in three forms: the definitional drawing, the process plan, and NC tapes (command sequences for NC tools). These artifacts are shown physically in Figure 9 and logically in Figure 10. All are sent to the shop to govern the physical manufacture of the parts in Figure 11.

Figure 12 shows the complete logical diagram, which we can now treat as the description of a *part-making system.*

This brief tour through batch manufacturing shows clearly that a very considerable amount of information processing occurs, and that most of it is done by humans. If only one part of a given kind is needed (as is often the case in some industries), the planning, programming, and documentation costs can exceed the physical manufacturing costs by an order of magnitude. As more physical copies of a part are made, however, the "front end" costs can be amortized over a larger base because much of the planning, programming, and documentation need be done only once. The organization shown in Figure 12 came into being over the last 10 to 20 years as industry's way of accommodating NC machine

Figure 3



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[5] Gleason Works is a progressive manufacturer of specialized gear making machinery, more than 100 years old. Gleason employs about 2200 people and recently has had gross sales of $70 million, of which more than half have been export sales.

Figure 4

Figure 5

Figure 6

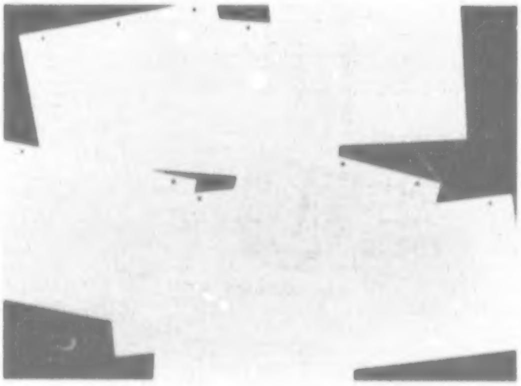


Figure 7

Figure 8

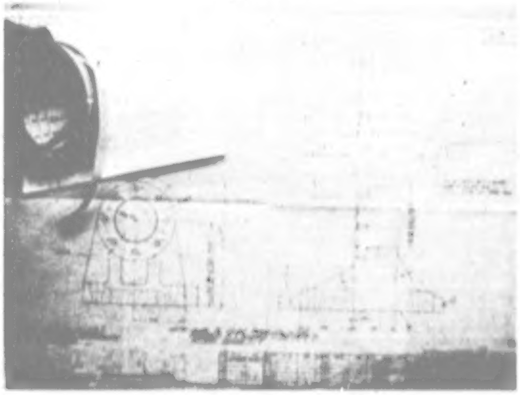


Figure 9

Figure 10

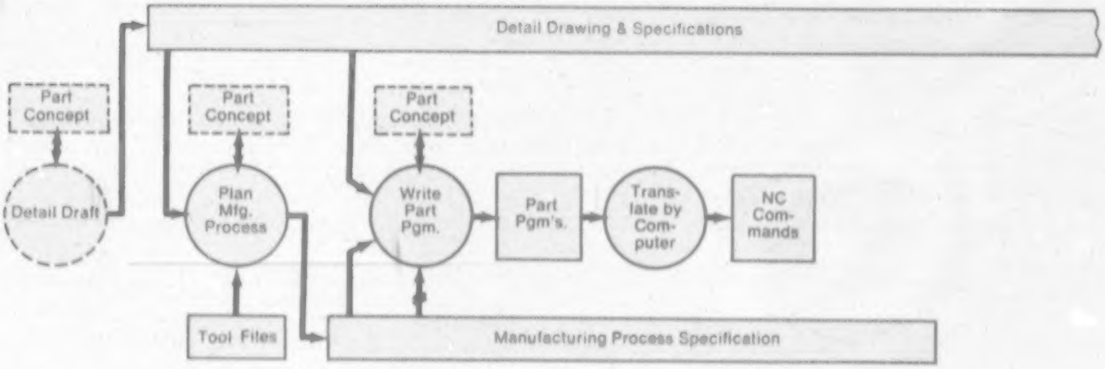
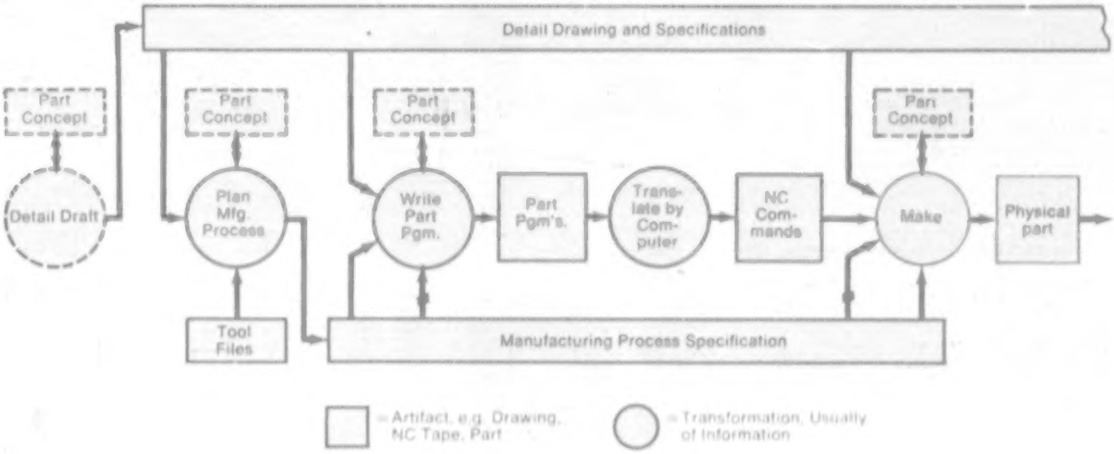

Detail Drawing & Specifications
Part Concept
Part Concept
Part Concept
Detail Draft
Plan Mfg. Process
Write Part Pgm.
Part Pgm's.
Trans-late by Com-puter
NC Com-mands
Tool Files
Manufacturing Process Specification

Figure 11

Figure 12


Detail Drawing and Specifications
Part Concept
Part Concept
Part Concept
Part Concept
Detail Draft
Plan Mfg. Process
Write Part Pgm.
Part Pgm's.
Trans-late by Com-puter
NC Com-mands
Make
Physical part
Tool Files
Manufacturing Process Specification
= Artifact, e.g. Drawing, NC Tape, Part
= Transformation, Usually of Information

tools. Prior to NC, drawings often were passed directly to skilled craftsmen in the shop. The craftsmen did manufacturing planning for each part largely in their heads.

The invention of NC in 1950 (at M.I.T., using World War II servo technology, and intended initially for military production) set in train a series of changes in manufacturing whose eventual end is probably the fully automated factory. Fundamentally, NC takes the control of tools out of the (literal) hands of craftsmen and makes them controllable from "above," through information that can be manipulated in computers, transmitted electronically, and stored compactly. The basic issues in manufacturing automation are: from how far above the tool should control be exercised, and how much of the currently manual planning, programming, and documentation work can be automated economically?

Industry's approach to automation, and earlier to mechanization, has been evolutionary rather than revolutionary. Tools were improved gradually over the centuries, with NC's arrival in the 1950's being in retrospect a momentous event. Part programming systems were developed late in the 1950s and in the 1960s. These are now in widespread use. The traditions of the industry led it to attempt, in the 1960s and currently, a further "leftward" step in terms of Figure 12: automation or partial automation of part programming. These efforts have not been very successful, for reasons too complex and ill-understood to discuss here.

The alternative to the evolutionary approach is the systems approach to automation. It is the avenue chosen by the Production Automation Project. Figure 13 conveys the basic idea: define a system in terms of endpoints—part descriptions and parts, in our case—and then determine systematically what must be done by the intervening process, "Mfg.," given the constraints imposed by extant investments in equipment and skills.

Our project plan calls for three sequential stages. Figure 14 describes Stage 1 graphically. We completed Stage 1 a few months ago, and we are now completing a comprehensive report detailing our findings, conclusions, and hypotheses.[8] Stage 1 took considerably longer than we had anticipated for several interesting reasons. Firstly, computer-based technology for manufacturing is burgeoning in the form of numerous new commercial systems which purport to solve various phases of the manufacturing problem. This technology is difficult to survey because there are few standards on which to base comparisons, almost no objective principles defining what systems "should" do, and no agreed ways to talk about manufacturing systems abstractly.

Figure 14

Stage 1

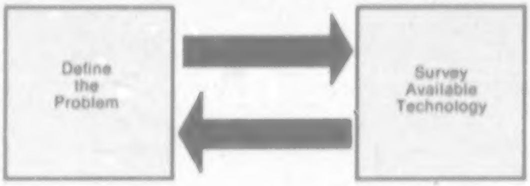
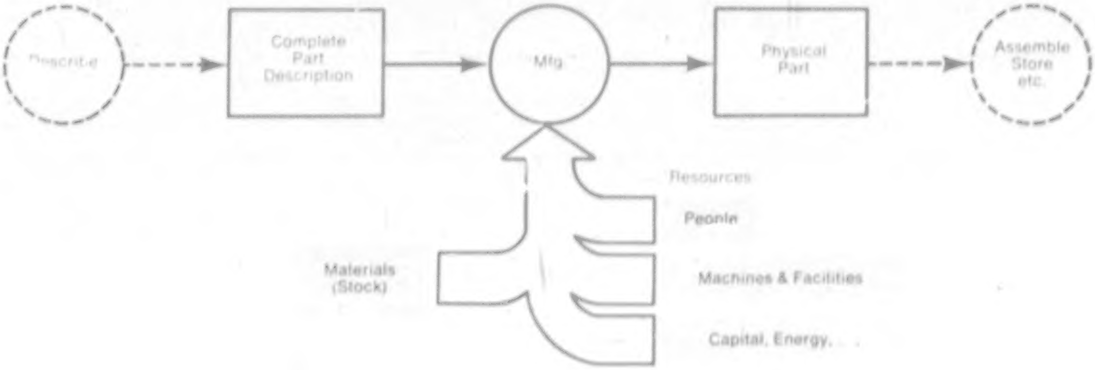


Figure 13



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[8] *Discrete Part Manufacturing: Theory and Practice*, to be issued in 1974.

These problems, however, simply manifest the central problem in manufacturing engineering. There is no accepted and publicized scientific base for the field. Thus we were unable in Stage 1 to define concisely and objectively the problems we wanted to solve until we took the bold step of postulating a mathematical meta system in which to model manufacturing. Once we had done this, both our problem-definitional work and our technology surveys fell into place. Whether our meta system is a good one can only be decided pragmatically a few years hence.

Stage 2 of the Project is shown as a series of objectives in Table I. We are now in Stage 2A and expect to attain its objectives for usefully large classes of industrial parts and material removing processes. Progress in Stage 2B is strongly contingent on meeting successfully the objectives of Stage 2A. We are at least one to two years away from Stage 3, which covers staged feasibility and practicability tests of prototype systems. These tests, if successful, will be followed by efforts to promote the new technology while simultaneously extending and improving it.

The Gleason Input

Gleason's role in the Project has several facets that might be summarized as providing practical experience, providing personnel to do specific tasks when their skills are appropriate, and providing a test bed, first for ideas and later for experimental systems.

Gleason personnel contributed strongly to the technology surveys, for example, and will be closely involved with the performance goals and user-interface characteristics of experimental systems. At present, while university personnel are engaged in theoretical and exploratory phases of the work, Gleason personnel are analyzing a sample of Gleason parts to determine certain characteristics of particular importance in our planned approach.

In conclusion, we invite all interested parties to view our forthcoming report as a serious attempt to lay some foundations for manufacturing engineering, and to direct serious criticism at it. Our particular approach may prove abortive, but others must take up the work if we are to reap the benefits which automation can offer.

Table I

Stage 2: **Research & Experimental Development**

- Stage 2A: Develop Systems to Describe
  - Parts
  - Tools
  - Processes
- Stage 2B: Develop Algorithms for
  - Planning
  - Control of Manufacturing Processes

MAGNETIC SEPARATION IN THE MINING AND PROCESSING INDUSTRIES

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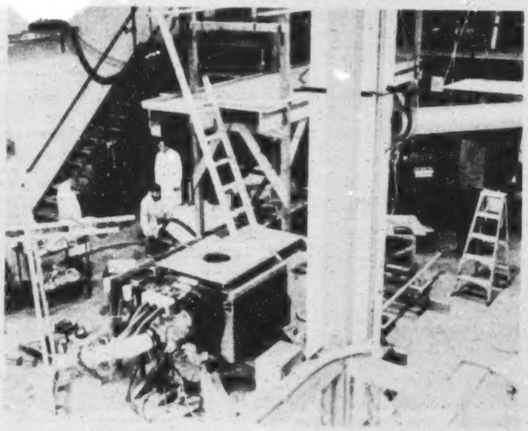
Magnetism has been used for many years to separate magnetic particles from a mixture of non-magnetic particles. It has been used, for example, to remove steel chips from breakfast cereal and other processed foods, or to extract magnetic iron ore from a mixture of non-magnetic minerals.

A variety of machines have been developed for this purpose. They consist essentially of a rotating drum or a traveling belt that carries the mixture to be separated over or under the poles of a electromagnet or permanent magnet. However, magnetic separation in the past has been restricted to the few materials which are strongly magnetic, and to particles of relatively large size. Magnetic separation has therefore been of rather restricted utility.

Broad Application of Magnetic Separation

Recent achievements at the Francis Bitter National Magnet Laboratory at MIT now make it possible to apply magnetic separation techniques to a much larger class of materials that are so weakly magnetic that they do not adhere to ordinary magnets, and to particles of such small sizes that they remain suspended in water without settling—the so-called colloidal materials. Powerful research magnets at the Francis Bitter Laboratory are shown in Figure 1. This development has very exciting and far-reaching implications because it provides man with a new method of dealing with colloidal particles on a large scale. Heretofore, this has not been economically possible. The problem of dealing with small particles is fundamental to a variety of areas. Mineral processing, for example, involves the extraction of valuable components from minerals. No matter how rich an ore may be, if its value is too finely divided, extraction is economically impossible and the mineral is discarded as mine tailings. In many mining operations, more value is discarded with tailings in the form of unrecoverable slimes than is extracted.

Figure 1



In some mineral applications objectionable impurities can be removed through high-gradient magnetic separation, as the process is called.

One application already realized on an industrial scale is the purification of kaolin, a white clay used in paper coating. This is done by the removal of colloidal titanium dioxide, which is stained by other impurities.

Another very important application of this sort, already demonstrated in the laboratory, is the removal of sulfur from pulverized coal.

A further application is the purification of water—including drinking water, and industrial and municipal waste—by the removal of suspended organic and inorganic contaminants, as well as certain desolved contaminants.

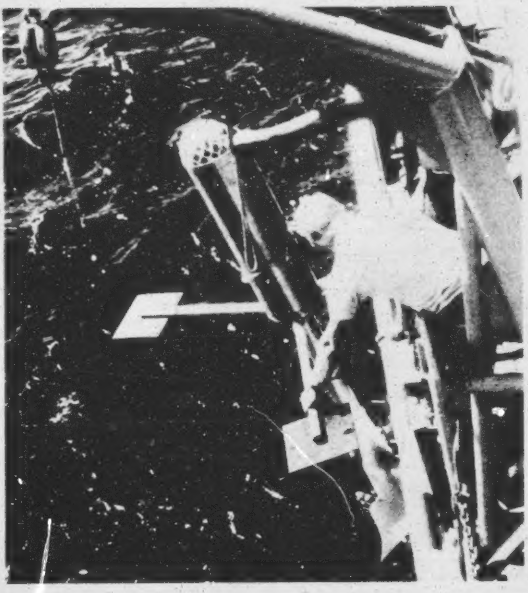
Applying Research to Need

The development of these new methods of magnetic separation represents a very interesting case history in technology transfer and the role of science funding policy. The basic knowledge in magnetism and magnet technology required in the development of these new techniques evolved over a period of some 20 years within the physics community. Sophisticated magnets were used to deflect and focus high-energy particle beams, and to perform certain solid-state and plasma-physics measurements. However, this body of knowledge never found its way from the physics community into the practical world, the community of people concerned with mineral processing, mining equipment construction, sanitary engineering and other related areas. The first transfer occurred some five or six years ago as a by-product of other research.

High-gradient magnetic separation was developed at the MIT National Magnet Laboratory in conjunction with a basic research project involving a search for elementary particles carrying magnetic charge, the so-called Dirac monopole, an elementary particle that has never been found, although its existence was predicted some thirty years ago. The most likely source of such particles is deep-sea sediment, a colloidal mixture of finely divided minerals. High-energy magnetic monopoles arriving with the cosmic radiation would be slowed by ocean water and trapped in the magnetic components of deep sea sediment. Only a very small fraction of deep sediment is magnetic. Since it is difficult and expensive to obtain large quantities of sediment from great depth, we developed a simple device that could be dropped from an oceanographic vessel (Figure 2), would pump large quantities of deep-sea sediment through a magnetic separator on the ocean bottom, and would then float the collected magnetic particles to the surface in a capsule provided with a radio-beacon and a flashing strobe light to facilitate recovery. The results of this search were negative in the sense that no magnetic monopoles have been found. It was only later that the technique was developed in connection with important practical applications.

The first applications were brought to our attention by recent MIT graduates working in the mineral industry who came back to MIT for advice in solving problems they perceived to be magnetic in nature. The first such problem involved the extraction of molybdenum, tungsten and other metal oxides being discarded in large quantities with mine tailings because they were too finely divided for economic recovery by any known process. The extraction of molybdenum appeared economically feasible on the basis of laboratory tests, but the mining industry involved was not interested in undertaking pilot-plant development because, in their words, "We are in business to make money not molybdenum." This represents one of many cases in which private mining interests based on the profit motive only do not coincide with the national interest. Government intervention is necessary for the sake of conserving both domestic natural resources and import dollars.

Figure 2



Kaolin Success

The second application that happened to come along, by contrast, was an immediate success. It involves the purification of kaolin, a white clay used in paper coating. Resources of naturally white kaolin are being rapidly depleted. The much larger quantities of contaminated kaolin can not be whitened by chemical bleaching processes. A Georgia kaolin company had discovered that the discoloration in certain grades of kaolin can be removed magnetically on a laboratory scale, but all of its attempts to accomplish this purification on an industrial scale were unsuccessful. After extensive dealing with all the manufacturers of magnetic separation equipment and a number of consultants in the field of mineral beneficiation, this company returned to MIT prepared to try the novel and relatively untested approach. Following successful laboratory tests, three successively larger machines were built for the Georgia kaolin company, thus translating sophisticated magnet technology from the physics community to the practical world.

The economic benefits of this application were not restricted to the savings in process cost over competitive chemical methods. The new method also made possible the beneficiation of kaolin deposits previously not amenable to economic recovery, and the tangible reserves of kaolin in the U.S. have increased many-fold as a result.

How It Works

Before discussing further applications I might explain the principles involved in high-gradient magnetic separation. The technique is based on a fact which is rather obvious in retrospect—that the force exerted by a magnetic field on a magnetized particle is proportional not only to the field intensity, but also to the field gradient. For a magnetized particle to experience a magnetic force, in other words, the magnetic field must vary appreciably over the size of the particle. If the magnetic field does not vary appreciably, the forces exerted on the north and south poles of the magnetized particle will simply cancel.

Ferromagnetic materials are easily magnetized by an applied field, but their magnetism saturates, as illustrated in Figure 3. Paramagnetic materials are harder to magnetize, but do not saturate. They are not normally considered magnetic because they are not attracted appreciably by ordinary magnets. But in a very strong field, they can also become magnetized.

This phenomenon is illustrated in the next two figures with powdered manganese oxide, a weakly paramagnetic material. In Figure 4, the powder is not attracted sufficiently to the blunt end of a magnetized iron rod. But it is picked up by the pointed end of the same rod in Figure 5. For a magnetic force to appear, the field must vary sufficiently rapidly so that the north pole and the south pole of the particle will experience sufficiently different field intensities.

To generate fields of such a high gradient requires ferromagnetic structures whose size is comparable to the size of the particles being separated. The various structures used in conventional separating equipment were simply too coarse for the job. As we attempted to refine magnetic pole geometries, we found our designs approaching a very common type of material: steel wool. We found that a matrix of finely divided ferromagnetic material, such as steel filaments in the form of a woven fabric or tangled mass, produced very large volumes of high gradient field in the form of magnetic flux that emerges from the numerous sharp points and serrated edges. Such matrix material also has a very large surface area on which to collect magnetic particles. The main obstacle to the use of such

Figure 3

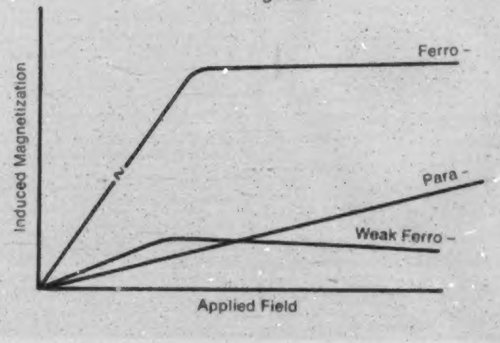


Figure 4

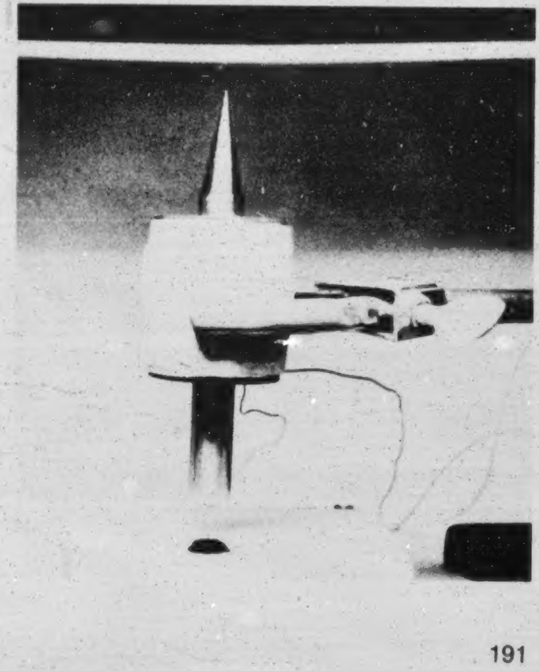
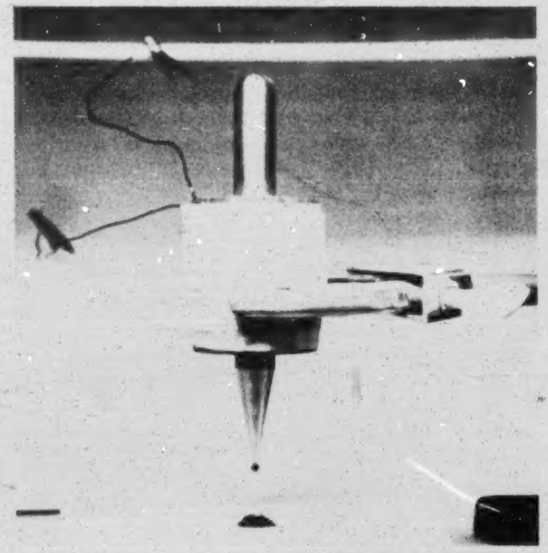


Figure 5



finely divided matrix materials is the fact that to be at all useful they must contain much void space. Compressed steel wool, for example, is only 5 per cent solid, 95% void. It is impossible to magnetize such a material by means of conventional magnets because it will not conduct magnetic flux. To magnetize matrix materials effectively requires sophisticated magnet technology such as has been developed, for example, in the construction of bubble chambers for high-energy particle analysis. The availability of this special know-how enabled us to solve a problem that was beyond the knowledge of experts in mineral beneficiation. However, technology transfer does not end with the laboratory solution of a given problem. It requires sustained interdisciplinary cooperation and a great deal of effort.

Other potential applications of high-gradient separation emerged very soon after solution of the kaolin problem. I shall describe the most obvious of these briefly.

It had been known for some time that about half of the sulfur in coal, the inorganic sulfur, is contained in the form of pyrite, which is very weakly magnetic. Since coal itself is non-magnetic or even weakly dia-magnetic, attempts were made to remove inorganic sulfur from coal magnetically. The conclusion of these earlier tests was that the process is possible in principle, but that existing magnetic separators were not adequate to perform it on an industrial scale at an acceptable cost. Recently, however, a doctoral thesis done at our laboratory by a graduate student in chemical engineering from Brazil, with support from the Brazilian government, has shown that high-gradient separation can remove pyritic sulfur from coal pulverized in the conventional manner and that it can be done at acceptable cost, about 75 cents a ton.

Extending Mesabi Resources

Another very important application involves the extraction of so called "non-magnetic" taconite, the most abundant iron ore of the United States. Taconite has been mined for over a century in the Mesabi Range, a vast deposit extending from Minnesota through northern Wisconsin into Michigan. This ore forms the backbone of the Great Lakes steel industry. Substantial quantities of it are also exported from Duluth, terminal of the St. Lawrence Seaway. In about 1960 the so-called direct-shipping ores had been depleted. The remaining deposits were no longer sufficiently rich to be used directly in blast furnaces, which require ores of at least 65% iron content. The remaining ore in the Mesabi Range was as poor as 35% in many cases. Doomsday in the Mesabi Range was averted by the development of a new technology: pelletizing. The low-grade ore was ground to a fine powder, taconite was extracted from this powder by means of magnetic drum separators and flotation processes, and the fine black concentrate of taconite was formed into fired ceramic pellets of adequate size and strength to be used as blast furnace charge.

Now, after ten years of pelletizing, a new tragedy has struck: the reserves of magnetic taconite approach exhaustion, and the vast quantities of remaining ore are so-called semi-taconite or non-magnetic taconite such as that produced at the Butler Mine of the Hanna Mining Company, shown in Figure 6.* There exists at present no economically feasible process for concentrating this relatively non-magnetic material. High-gradient separation, however, is capable of doing so and thereby extending the iron ore reserves in the Mesabi Range almost indefinitely. A continuous high-gradient separator, installed at the National Magnet Laboratory, is shown in Figure 7. This separator uses a moving matrix in the form of a carousel with a number of chambers as illustrated in Figure 8. Pulverized taconite is introduced while the matrix is magnetized, and the non-

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* Reprinted from the May 1967 issue of *The Hanna Miner*.

Figure 6

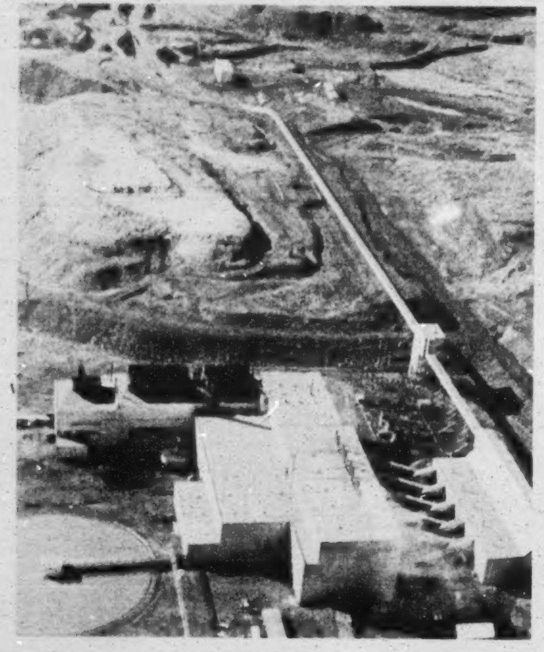


Figure 7

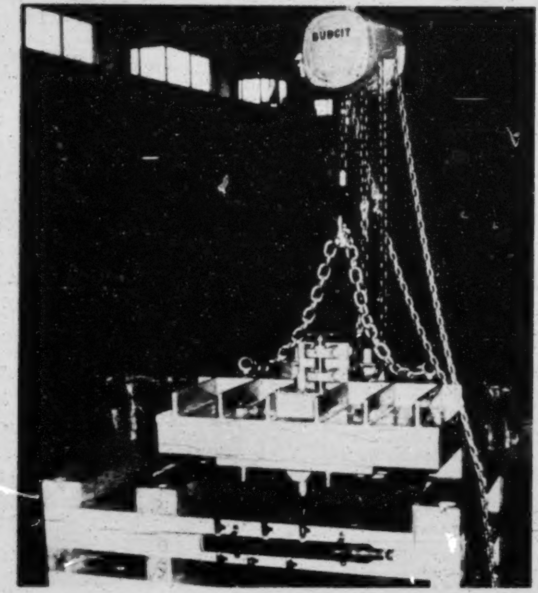
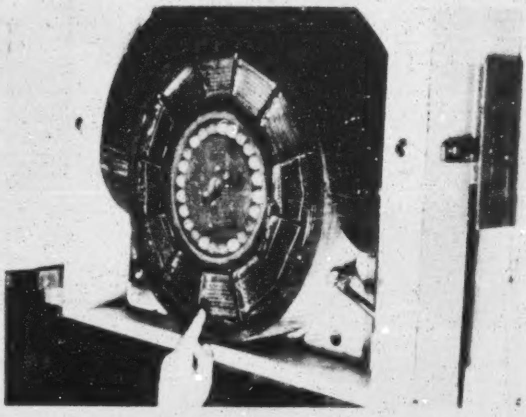


Figure 8



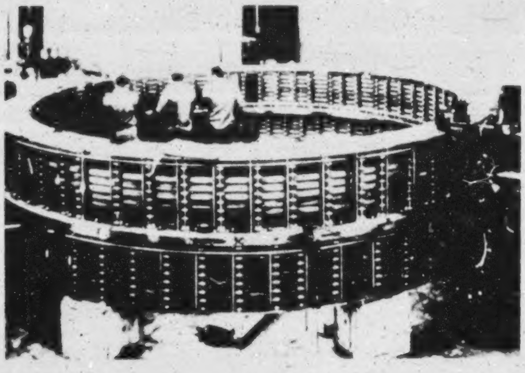
magnetic fractions are allowed to flow out. The rotating carousel then carries the retained magnetic fractions to a field-free region, where they are washed out. This relatively small machine handles more than three tons an hour.

Pollution Application

In conclusion I would like to describe what may well turn out to be the most valuable application of all, the treatment of water. It has been known for a long time that certain impurities, in particular coliform bacteria, can be removed from sewage by adding colloidal iron oxide. Unfortunately the process is not very useful because the removal of colloidal iron oxide in itself presents a problem which has never been solved satisfactorily on a large scale. One can filter a swimming pool, but filtration is unthinkable for say Lake Erie or even the output of a large municipal sewage plant. High-gradient magnetic separation makes colloidal filtration feasible by permitting flow rates 100 to 1,000 times faster than rates associated with filtration. Field tests conducted over a period of six months in collaboration with the Metropolitan District Commission (MDC), the agency responsible for water and sewage treatment in greater Boston, has persuaded them of the feasibility of magnetic water purification. Magnetic Engineering Associates of Cambridge is currently working under contract to study the cost of purifying the Charles River Basin by means of a barge-mounted magnetic separator which continuously removes contamination from the river bottom sludge. The process under development, on a laboratory basis thus far, performs the function of removing coliform bacteria, other suspended organic solids, odor, biological oxygen demand, and suspended inorganic colloidal substances. Of particular interest is the fact that the process also removes virus contamination, certain trace chemicals, and certain components of dissolved nutrients such as phosphate, a process commonly associated with tertiary sewage treatment which has never been economically feasible before. But the process can now be feasible with the use of a large superconducting magnet, such as that at Argonne National Laboratory in Illinois, shown in Figure 9. The Argonne magnet is used to generate a 30-kilogauss field in a space 14 feet in diameter and six feet high. It cost $3 million and because of its superconducting feature uses only a negligible amount of electric energy. The advent of high-gradient separators using magnets of this type will make it economically feasible to decontaminate large natural bodies of water, perhaps even Lake Erie. There is no question in my mind that sooner or later all sewage treatment will be performed on the basis of high-gradient magnetic separation.

The readers might wonder at this point why such an obviously important application of science should not find its way into widespread use spontaneously, now that its value and feasibility have been demonstrated both in the laboratory and in at least one industrial application.

Figure 9



Incentive Lacking

The answer is that various industries that need the new technology are unable to conduct the additional research and development needed to reduce high gradient magnetic separation to practice in each specific field. They are unable not only because they do not possess the interdisciplinary talent required, but also because in many cases there exists no demonstrable self-interest, as in the case of the mining industry cited previously. This is true in most mining operations, not just in the case of molybdenum. The kaolin industry represents a relatively rare example in which immediate financial benefit to the mining operator was obvious.

Pollution control, in its various forms, is an even more striking example because decontamination always involves a deficit, and the less pollution control technology exists, the less any operator will be required to invest. If coal cannot be economically desulfurized, a mining operator will simply have to be permitted to sell high-sulfur coal. No municipal or industrial waste-water treatment facility can be required to perform any decontamination process which is not technologically feasible. For these and several other reasons, the application of high-gradient magnetic separation to pollution controls needs support outside of industry.

The RANN program needs a number of administrative adaptations to accomplish what is in reality a new mission for science. These include a fundamental revision of the basic patent philosophy to stimulate industrial participation in the RANN mission, and a significant change in the traditional review process to make possible the intermediate kind of research required in many applications, the research which is neither "basic" nor "hardware-producing," and which cannot be judged or guided by either the academic or the industrial community.

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IMPLICATIONS OF NEW TECHNOLOGIES

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Technology has always been important primarily as an agent of social change. However, the people who have created or applied new technology generally have thought last of all, if at all, of the real implications of that technology for society. Certainly Richard Arkwright and James Watt, for example, were not thinking of the kind of world that was to come out of their inventions. Nor have most other inventors throughout history thought much about the social implications of their work. This is still the case today.

However, this situation is changing. As we move from an advanced industrial society into a post-industrial society, we are re-ranking our social priorities. And we are becoming much more concerned with trying to apply technology to the achievement of certain specific social objectives. I would like to make four observations about this change.

National Alternatives

First, the very process of defining national alternatives is something quite new, and requires a great deal more effort and attention. We should all welcome the initiatives by the National Science Foundation and other elements of the Federal Government to promote the exploration of what alternatives are open to us, and what things we must do to pursue them. We must all become much clearer about what our order of priorities should be. We must also do a lot more to maintain our technological lead, which has been somewhat eroded, and to gear our technology to the order of priorities we adopt.

Incentives

The second problem area is the process of applying technology to our priorities. Here I would tend to feel that we need more private sector activity, stimulated by a structure of incentives developed by the public sector. We are beginning to see some of this coming about, and some of the leadership of it is coming from the National Science Foundation. The Experimental R & D Incentives Program of the National Science Foundation is, I think, an example of a real reordering of the institutional relationships between the private and public sectors.

One of the biggest problems we have before us is that of finding ways to make it profitable for private-sector business institutions to do the new things that society now wants done. We have made it profitable for business to produce a broad range of consumer goods and services, but we have not created profitable markets for many of the services that now have high social priorities. In the worst of our city ghettos, you can buy relatively cheap, relatively high-quality consumer goods. But you can't buy many other things that you ought to be able to buy, in the way of education, in the way of prevention of crime, in the way of housing. When market forces are lacking, we have great difficulties in delivering these essential services.

So we have to develop the incentives that will attract private business to delivering some of these services. Once we have defined a series of national objectives and ranked them in an order of priority, we have to learn how to create the incentives which attract the capital, which attract the management and, above all, attract the dynamic institutions to working toward the attainment of these objecitves. This is a very important, very interesting and very key problem. My guess is that we could learn a certain amount in this area by looking at foreign examples. Both Germany and Japan, for instance, have very interesting models in terms of relationships between the private and the public sectors. Both are indeed worth our study.

Advanced Technology

The third area on which I would like to comment is that of learning how to build profitable business around advanced technology. My company has a partnership in France with the Rothschilds, and one of the sayings in the Rothschild family is that over the years they have lost money in three ways. They have lost it on horses, which has been the fastest way of losing it. They have lost it on women, which has been the most pleasant way. And they have lost it by investing in high technology, which has been the most certain.

I think this applies to us today. I met earlier today with 40 prominent venture capitalists of this country. One of the problems we have is that we are moving out of a period in which we gave away a lot of engineering to sell a machine, into a period where the machines are starting to be quite incidental and the engineering is becoming the principal consideration. In many of our businesses, we do not have the proper incentive structure or the right kind of entrepreneurial drive to handle the new mix of intellectual input and technical and business skills that is required.

We have a lot to learn about building profitable businesses around advanced technology. It is going to be very important to us as a country that we do so. We can already learn a lot by closer study of the multinational corporations—which are among the most interesting institutional innovations of the last 25 years. They have turned out to be some of the most effective agents for transferring technology and among the most dynamic means of achieving some of our social objectives.

Value Systems

The fourth point I would like to make concerns a reordering of our approach to how we organize and employ people in a post-industrial society. Value systems—and particularly our attitudes toward work—are changing very, very rapidly. The companies that retain the old views of how you classify and compensate people, how you organize them and what incentives you provide for them will find the going tougher and tougher. On the other hand, companies that take a completely fresh view of what people's values are and what their attitudes toward work are, and who rethink their approaches to the organization of work, are the companies that will really move out in front in this age.

The area of value systems as applied to work will be one of the most dramatic areas of change in the next few years. This change will be tremendously important to our productivity. My guess is that we will find a very substantial reordering of our approach to the mix of work and education throughout our life. We will probably begin to experiment with work at a much earlier age and with more extensive education in the middle and toward the end of life. I think also that we will structure systems in which large companies begin to farm out much more of their work to partially owned subsidiaries, run by people who have their own ideas of how they want to organize their output, and who do it in their own way, in their own time.

I think Route 128 might have been a very different story if some of the older, well-established companies had taken a quite different view of entrepreneurial incentives for highly skilled, highly gifted people. The older companies could have structured partially-owned subsidiaries, for whom they did the financing and marketing and production. Meanwhile, the subsidiaries would have got the product innovation and the research and the product servicing done by pools of people who had a real stake in what they were doing.

Conclusion

I think that our ability to apply technology will be tied very largely to our ability to make material innovations in our private and public institutions and in their relations with one another. My guess is that the greatest change will be in the public-private interface. I think that in this change we have our greatest chance as a nation to achieve a much stronger dynamic in the next stage of our development.

I would like to close with a quotation from Alfred North Whitehead. He said, "It is the business of the future to be dangerous and it is among the merits of science that it equips the future for its duties."

In the immediate future, there will be less security and less stability than in the immediate past. It must be admitted that there is a degree of instability that is incompatible with civilization. But on the whole, unstable ages have been great ages.

RESEARCH UTILIZATION

RANN APPROACH TO RESEARCH UTILIZATION

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The RANN approach to research dissemination and utilization can be summarized in three words:

GET IT DONE!

But as we all know, there is no easy way to insure that better ideas will be adopted, or that better techniques will be used. People and institutions resist change—even those who know full well how important it is to adopt new ways of doing things. We are all creatures of habit.

American businessmen have learned that innovation is an indispensable way of life in our economic system, and they face daily reminders of the fact in the marketplace. In this environment there is little place for research for which there is not a clear utilization objective.

Business carries out research utilization by assigning priority—and dollars—to product development and marketing. For every dollar invested in the research that produced the product, the pressures of the marketplace force industry to invest 10 to 20 dollars in research utilization. Industry's experience is that if it does not assign priorities in this way, it takes the chance that the investment in research will not pay off in sales.

The government approach has been quite different. The emphasis has been on research—usually 10 times as much as on utilization.

An exception is the Department of Agriculture, which for almost 60 years has operated a service that disseminates the findings of agricultural research to farmers and other interested persons throughout the United States. This system is the well-known Agricultural Extension Service. It operates through the land-grant colleges in every state, and through agents in almost every county. It is one of this nation's most effective and efficient means of delivering scientific and technical knowledge. It has contributed importantly to the world leadership now enjoyed by the American farmer.

There are very good reasons why industry and government have distinctively different research utilization patterns.

The private sector is motivated by profits, by a desire to capture markets, by the pressures from competing firms and industries—in short by the free market system.

In government—with the exception of wartime—there have been few incentives as powerful as those of the marketplace. The business of government has *not* been the marketing of products or even of technology.

But things are changing.

The realities of the energy crisis, the pressures to clean up the environment, the demands for greater productivity—in short, the three national needs we in NSF are trying to meet—are areas where there simply are *not* enough resources in government to content ourselves with less than the best solutions.

And best solutions must be communicated broadly in order to be effective.

That is why it is the responsibility of the government to do sufficient marketing to determine that conditions are right for the introduction of an innovation. If it finds that conditions are not right, then the government must feed this back into the decision process. If conditions are right, then government should involve appropriate producer groups in carrying innovation to its practical conclusion.

User Involvement

In the RANN program, we are working to use all available means to fulfill this responsibility. We are working with users before the award of research grants and contracts, during the research programs and on completion. Our intention is to establish a system that will be as useful for RANN as the Extension System has been for agricultural research.

The RANN Research Utilization program builds on seven years of NSF experience in developing and operating an intergovernmental science program. This effort pioneered in helping state and local governments find ways to improve their ability to use science and technology. It has also helped the Federal government move in the direction of applying technology to civilian sector problems and needs.

The RANN Research Utilization Office has four basic functions:

- **We are responsible for developing policies, programs, procedures and plans to promote the full utilization of RANN research results in national need areas.**
- **We attempt to stimulate the development of public and other user capability to implement RANN research results.**
- **We plan and arrange for proof-of-concept demonstrations leading to replication of successful RANN project results elsewhere.**
- **We have the responsibility to promote full dissemination and diffusion of RANN research results.**

To the maximum degree possible, we try to use the research utilization capabilities of other Federal, state and local agencies as well as the private sector.

Let me be a little more specific. The research utilization job begins *before* a research grant or contract is awarded. We ask users to identify *their* problems and *their* needs. We get them involved in priority setting. When we receive a research proposal, we require that it have a utilization plan. And we invite users to participate in our decision-making by judging the merits of proposals.

The user is also involved during the research program in helping us determine research strategies. In some cases there is joint funding with Federal mission agencies, or there may be other arrangements for user cost sharing or joint management. Users are invited to participate in site visits. Program briefings are arranged for users. And in many cases, the program includes preparation of user manuals.

And, of course, we must communicate with the user when the research is completed. Technical reports are provided to users and their review is invited. Technical articles are prepared for journals that they are likely to read. Special programs are organized at technical meetings. Popularized articles are prepared. Research synthesis activities of various kinds are undertaken. And in a few cases, we make films—some of which you have seen at this meeting.

But I would not want to convey the idea that our programs are cast in concrete. The research utilization function is still evolving and—I feel sure—still growing.

Major Thrusts

To give some feel for the evolution under way, let me mention a few major thrusts:

A current program provides for the distribution of RANN and other research findings to state and local governments, beginning with emphasis on energy and land use. This program is under the direction of Public Technology Incorporated and now involves 80 local governments.

We are helping to form a consortium of city and county governments in 28 of the largest urban areas with populations of more than 500,000, which will undertake to see how RANN and other research results can meet their needs. This group of governments expends more than 16 billion dollars and represents the interests of more than 34 million Americans.

In cooperation with the states of Tennessee, Colorado, and Oklahoma, we are working with the Agricultural Extension Service and the Environmental Protection Agency to develop a national environmental extension system that will be able to disseminate the results of not only RANN environmental research, but also the results of other Federal research activities to communities throughout the United States.

In all of these efforts, costs are shared and the aim is to bring them to self-supporting status as soon as possible.

Another program has been self-supporting right from the start. Through our Federal laboratory program, a group of 25 laboratories has been able to put together more than 180 projects bearing on needs of the civil sector. In compliance with the Mansfield Amendment, all of these have been fully funded by non-Defense agencies. The total funding of this program is in excess of $10 million.

Major Projects

Next, let me mention a few of the major research utilization projects that are under way.

One is an effort to use research results in establishing a program to preserve and restore the environmental values of the Lake Tahoe Basin. In cooperation with the bi-state Tahoe Regional Planning Agency, we are working to develop a master plan that will point research in the right directions and also lead to the use of research results in public and private decision-making processes.

In another project, we are developing a plan to help cities throughout the country with new approaches to planning and controlling urban growth. In most cities and suburban areas growth has already caused extremely difficult problems of managing resources and providing necessary services. A model policy and set of local ordinances have been developed in San Jose, California, with assistance from RANN. We will share the results of this project with other local governments in the first of a series of RANN field days that are to be initiated.

We are working with industry, an EPA National Environment Research Center and the Lawrence Berkeley Laboratory to determine the marketability of a spectrometer developed at Lawrence. This instrument quickly and accurately detects trace quantities of mercury and other contaminants in liquids, solids and gases. This device appears to have widespread potential including testing fish and other food products as well as effluents from industrial plants. Our studies indicate that the device can apparently be produced at a competitive price.

We are supporting a market analysis of waste-water purification processes being developed at the Oak Ridge National Laboratory. These processes promise to be very useful in achieving Federal standards in removing trace contaminants from various industrial effluents now being regularly discharged into the nation's waterways. Shortly we will make a hard marketing decision whether the Oak Ridge processes—solvent extraction and electrochemical extraction—should be brought to the proof-of-concept stage.

Market surveys and briefings to electrical utility companies indicate promise for a method developed at the University of Missouri to apply automatic data processing techniques to the operation of power system substations. Among the techniques that have come from this effort are improved relay control operations and fault detection.

One of the most significant of our research utilization activities is in support of the marketing of magnetic separation applications, described by Henry Kolm of the Francis Bitter National Magnet Laboratory in the productivity section.

Disseminating the Results

At the conclusion of the research process, RANN has the responsibility of disseminating the results to users and potential users. It is not always possible to know with certainty who will really take off and run with a research finding. We are still shaping our processes for disseminating research findings to perfect ways that are most cost-effective for everyone who has a need. We have established a RANN document center and arrangements are being made to distribute copies in both hard-copy and microfiche form.

Our RANN information dissemination program also supports digests and abstracting services as well as the utilization of various media in the dissemination process.

Finally, we sponsor and conduct a wide variety of workshops and conferences that bring researchers and users together to exchange information about requirements, results and plans for the future. Some of these meetings are small. Some are medium sized. This RANN Symposium is an example of how large a group can come together when an overview of the entire RANN program is presented.

We in RANN are committed to the fullest possible dissemination of research results in the same fashion as exemplified by the efforts of the Agricultural Extension Service. We are working hard in cooperation with other Federal agencies to close the gap in communication and understanding that exists between researchers and users and potential users. Currently, we are investing about $5.3 million in utilization activities. But RANN utilization is an evolving effort that is certain to grow as we move ahead to meet the challenge of ensuring the application of results to our national needs.

APPENDICES

APPENDIX A

ATTENDANCE LIST

The 1,531 persons (in addition to the NSF-RANN staff) who attended the first RANN Symposium represented a broad spectrum of backgrounds in industry, government, universities and the various disciplines of scientific, engineering and social science research. The following is the list of those who registrations were complete:

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An additional 8 persons registered and attended, but their registrations were incomplete.

APPENDIX B

RANN SYMPOSIUM DINNER MEETING

November 19, 1973

The following were seated at the head table:

Betsy Ancker-Johnson, Assistant Secretary of Commerce.

Raymond L. Bisplinghoff, Deputy Director, National Science Foundation.

Detlev Bronk, Chairman, New York State Science and Technology Foundation, and former President, National Academy of Sciences.

Charles A. Byrley, Director, Federal-State Relations, National Governors Conference.

Robert H. Cannon Jr., Assistant Secretary of Transportation.

Lloyd Cooke, Director, Urban Affairs, Union Carbide Corporation, and Member of the National Science Board.

Kenneth W. Dam, Executive Director, Council on Economic Policy, the White House.

William Donaldson, City Manager, Tacoma, Washington.

William O. Doub, Commissioner, Atomic Energy Commission.

Alfred J. Eggers Jr., Assistant Director, National Science Foundation.

Herbert I. Fusfeld, President, Industrial Research Institute, and Director of Research, Kennecott Copper Corporation.

Jack Golodner, Executive Secretary, AFL-CIO Council for Scientific, Professional and Cultural Employees.

Thomas F. Jones, President, University of South Carolina.

Hugh Loweth, Deputy Associate Director, Office of Management and Budget.

William A. Morrill, Assistant Secretary of Health, Education and Welfare.

Robert Nathans, Professor, Physics and Material Science, State University of New York, Stony Brook.

Russell D. O'Neal, Special Assistant to the Chief Executive Officer, Bendix Corporation, and Member of the National Science Board.

Russell W. Peterson, Chairman, Council on Environmental Quality.

John Sawhill, Associate Director, Office of Management and Budget.

Robert C. Seamans Jr., President, National Academy of Engineering.

Elmer Staats, Comptroller General of the United States.

H. Guyford Stever, Director, National Science Foundation.

James E. Webb, former Administrator, National Aeronautics and Space Administration.

Edward Wenk Jr., Professor, Engineering and Public Affairs, University of Washington.

Phillip C. White, General Manager of Research, Standard Oil Company of Indiana.

At the dinner, Dr. Eggers presented a special citation to Dr. Nathans recognizing the pioneering RANN-sponsored research on municipal service delivery that was carried out by his SUNY-Stony Brook team and that led to a substantial upgrading of the cost effectiveness of sanitation service delivery in New York City.

APPENDIX C

FILMS SHOWN AT THE RANN SYMPOSIUM

1. "The Edifice," 8 minutes, part of a 30-minute film, "Why Man Creates," produced by Kaiser Industries, available from Pyramid Films, P. O. Box 1048, Santa Monica, Calif. 90406.

2. "The Use of Knowledge Is Power," 8 minutes. Sound and color, series of stills, available in 16 mm film. A background presentation on the utilization of knowledge through history, with commentary on the problems of misuse of knowledge. RANN Document Center.*

3. "Help for Hail Alley," 5 minutes. Sound and color motion pictures, available in 16 mm and 35 mm film. Progress in the National Hail Research Experiment, a five-year effort to determine whether hailstorms can be suppressed in "Hail Alley," an area of Colorado and Nebraska where they cause millions of dollars in damage to crops every year. RANN Document Center.*

4. "Enzymes for Industry," 5 minutes. Sound and color motion pictures, available in 16 mm film. The progress and potential of a program to utilize enzyme technology to increase U.S. productivity, with emphasis on the possibility of converting cornstarch to sugar, thus reducing dependence on imports. RANN Document Center.*

5. "Lead, a Four-Letter Worry," 5 minutes. Sound and color motion pictures, available in 16 mm film. The results of research on lead contamination are applied in industry's efforts to reduce environmental impact of lead mining and smelting in a new mining area in the Missouri Ozarks. RANN Document Center.*

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*The RANN Document Center is in the Office of Intergovernmental Science and Research Utilization, National Science Foundation, 1800 G Street, N.W., Washington, D. C. 20550. For information on films contact Ms. Carmeen Adams, telephone (202) 632-0146, or Ms. Susan Sherman, Office of Public Affairs, telephone (202) 632-5703.

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APPENDIX D

EXHIBITS SHOWN AT THE RANN SYMPOSIUM

The following is a list of exhibits, together with names and telephone numbers of persons who can provide information on their availability.

MIT Magnetic Separator Exhibit, Dr. E. Maxwell, Massachusetts Institute of Technology (617) 253-5580.

Raytheon Magneplane High Speed Transportation Exhibit, R. R. Andrews, Raytheon Exhibit Services (617) 358-2721.

Johns Hopkins Fire Research Exhibit, Dr. Walter Berl, Applied Physics Laboratory, Johns Hopkins University (301) 953-7100.

University of Minnesota-Honeywell Corporation Solar Heat Pipe, Solar Energy Exhibit, Dr. R. C. Jordan, University of Minnesota (612) 373-3303.

University of Delaware Solar House Model, John Trela (302) 738-8481

General Electric Solar Panel for Heating and Cooling of Buildings, Arnold Cohen (215) 962-2770.

Westinghouse Solar Heat Pump, William Robinson (301) 765-3366.

AEC-Los Alamos Subterrene, Dr. John Rowley, Los Alamos Scientific Laboratory (505) 667-6677.

Westinghouse Slow Scan Television, William Finlay (301) 997-3010.

Lawrence Berkeley Laboratory Experimental Mercury Analyzer, Fred Kirsten, (415) 843-2740, extension 6341.

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